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METALS & ALLOYS

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The Magazine of Metallurgical Engineering

INCLUDING

CURRENT METALLURGICAL ABSTRACTS

BATTERY OF MELTING FURNACES AT BABCOCK & WILCOX COMPANY

OCTOBER
1933

VOLUME 4 NUMBER 10

PREVIEW OF THE NATIONAL METAL EXPOSITION—Pages A1-A32

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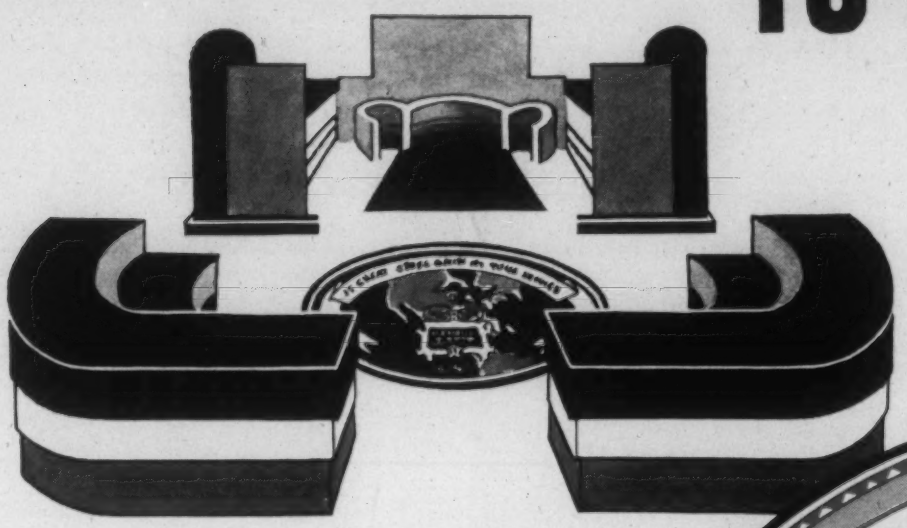

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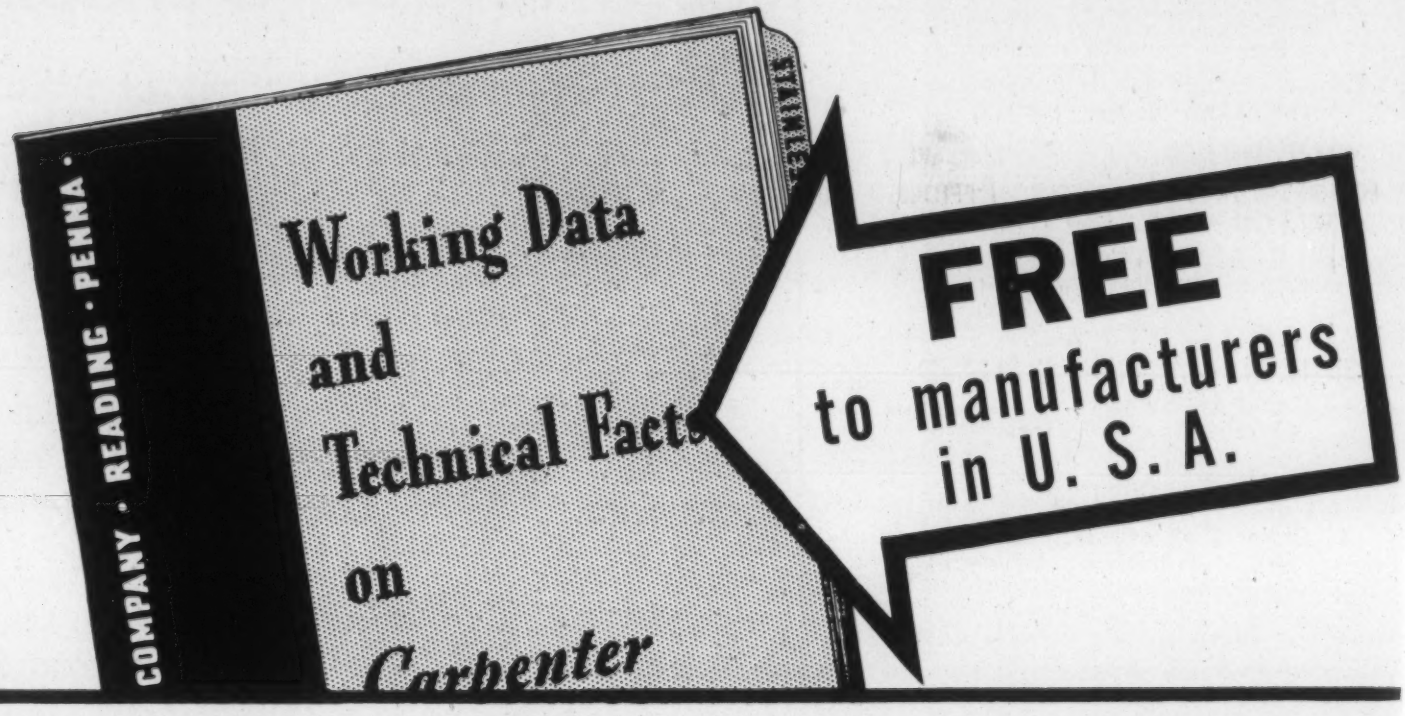

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HIGHLIGHTS

by H. W. GILLETT

(Rimbach pinch-hitting for Gillett)

Metals and Alloys on Shipboard

A number of articles discuss metals and alloys for marine use. Brands (page MA 317 R2) in pontoons, Whiting (page MA 317 R9) in cargo ships, Anon (page MA 320 L2) in destroyers.

Forging Temperature and Cutting Efficiency of Tool Steel

Goodtzoff and Kazeieff (page MA 325 R4) find that a high starting temperature and low finishing temperature of forging lead to best cutting efficiency.

Add Cement to Molding Sand

Maillard (page MA 330 R1) states many French foundries use 15% cement with molding sand, controlling the porosity by the amount of water.

Thermocouple for 1800°C.

Fitterer (page MA 335 R9) describes a couple of silicon carbide and carbon. Cold junction is water cooled and couple develops 300 microvolts per degree. This couple was found satisfactory for measuring temperatures of molten steel.

The Technical Man Sells His Services

The reviewer feels that this book (page MA 307 L1) should make an impression on young college graduates and there is no doubt that it will. For Horatio Alger impressed the writer sufficiently that he lived the stories as they were unfolded before him. In very few cases will the youngster get away with some of the stunts detailed by the author. The author failed to include the Roger's formula of marrying the president's daughter or—sister.

Speaking of Rarer Metals

We have indium (anon) (page MA 316 R1), tantalum and niobium (Aston) (page MA 307 R4) and thallium (Baxter and Thomas) (page MA 307 R4).

Welding in Ship Construction

Welding is becoming increasingly important in naval construction. This month there are articles by King and Montgomerie (page MA 322 L2) and Burckhardt (page MA 322 L9).

DO YOU want to know what metallurgical engineers are saying, the world over? Look in the Current Metallurgical Abstracts. Here are some of the points covered by authors whose articles are abstracted in this issue.

Books

The reviewers liked some of the books. Tieman's Iron & Steel Pocket Encyclopedia (page MA 307 L4) will find continual use as a reference book. Metallurgists will find much of interest in Bancroft's Applied Colloid Chemistry (page MA 307 L9). Read's book on "Our Mineral Civilization" (page MA 307 L6) can be read with understanding by the youngster and still appeals to the adult who already knows most of what the author has to say. The metallurgist will find this 165 page book interesting as a résumé of what metals are used for what major purposes and why, and the cost is only one dollar.

Nickel-Chromium Cast Irons

Cast Irons with nickel and chromium are covered by different authors: Müller and Hanel (page MA 308 R1), Urquhart (page MA 308 R 9), Morehead (page MA 310 L5), and Jungbluth and Pomp (page MA 310 L9).

Nickel Carbonyl is not the only Metal Carbonyl

Metallurgists know that Mond nickel is produced through the nickel carbonyl but seldom realize that there are other metal carbonyls. Indeed, one way of making very pure iron is from the carbonyl and carbonyl iron is often used for the iron base in scientific studies abroad. Mond discusses the metal carbonyls and presents a bibliography of 300 titles on them. (MA 328 L3.)

2% Silicon and Heat Resistance

2% Si in Ni Cr Fe alloys raises heat resistance 90% says Herrmann (MA 336 L1).

An Alloy Iron and Steel Index

There's a German index (MA 328 L4) to patents on alloy iron and steels, including U. S., Germany and 4 other countries, 1880 to March 1932, all indexed. The cost of one preliminary patent search will buy it.

Steel Decarbonization

Decarbonization of a soft steel by hydrogen, says Jacque (MA 334 R8) is slower if the steel contains copper.

Arsenic Removal from Iron Ores

By reduction and roasting, arsenic can be removed from iron ores, according to Ruff and Scheil (MA 336 R1).

Do Any Tests Forecast Life of Metals and Alloys

Browne (page MA 311 L1) discusses the accuracy of corrosion tests.

No More Valve Grinding!

Geschelin (page MA 310 L1) finds special alloys used as valve seat inserts.

Platinum Alloys Receive Attention

Alloys of platinum with copper and with nickel are investigated by Kurnakow and Nemilow (page MA 312 L6), with both copper and silver by Wise and Eash (page MA 308 L9).

Steel vs. Rubber Springs

Relative merits of steel and rubber springs were studied by Coil Spring Makers' Association of Sheffield (page MA 320 L6).

Sulphate Content in Chromium Plating Baths

Raub (page MA 316 R10) advises adjusting acidity of chromium plating baths with barium carbonate. Britton and Westcott (page MA 316 L7) state it is extremely difficult to deposit pure chromium from trivalent chromium salt solutions. Compositions of chromium baths are given in anonymous article in *Oberflächentechnik* (page MA 316 R1). Other articles on chromium plating by Korpium, Mangold, Udy and Kasper are abstracted this month (page MA 316 R4) and an article on chromium plating steel mill rolls by McKay (page MA 324 R6).

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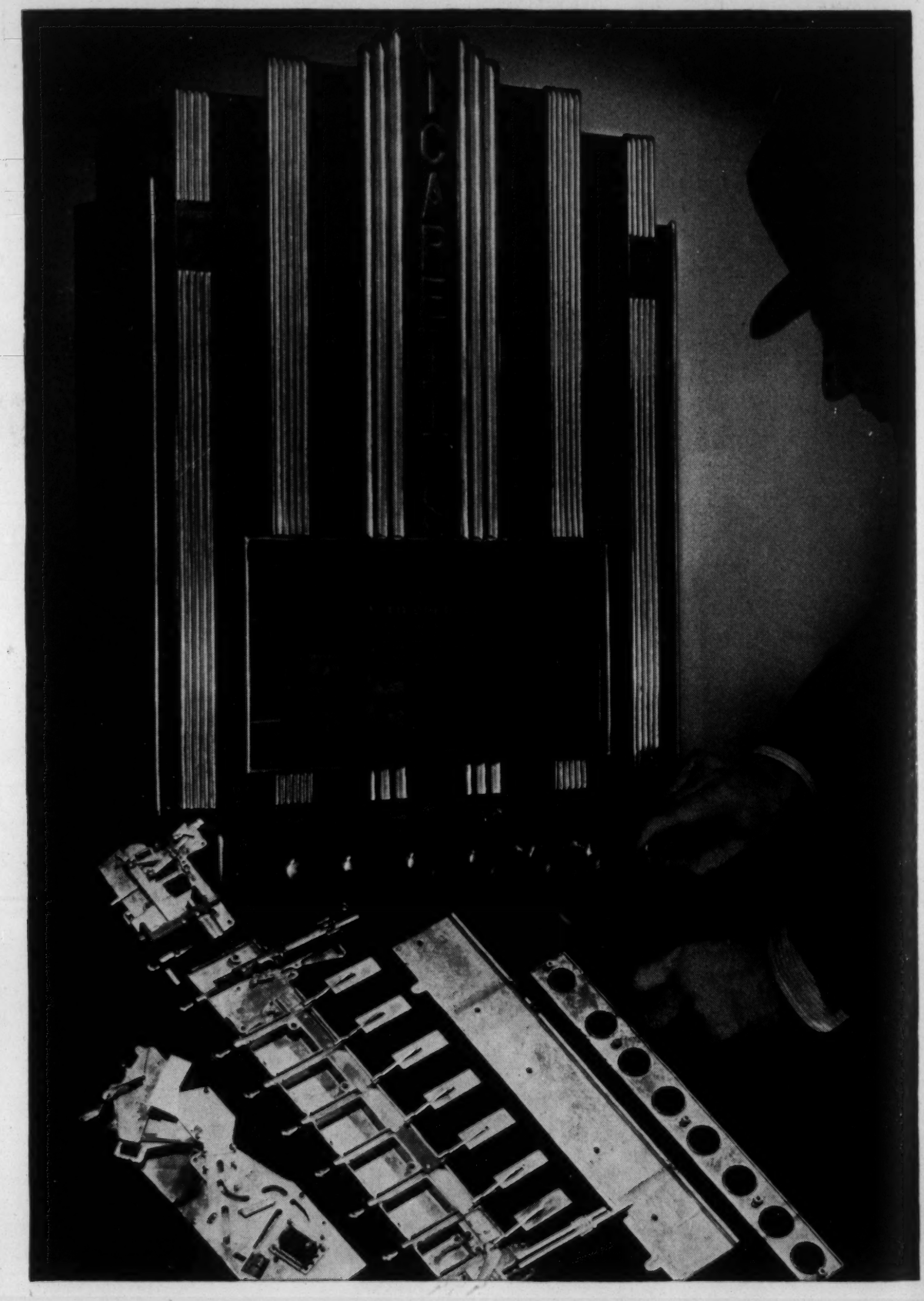

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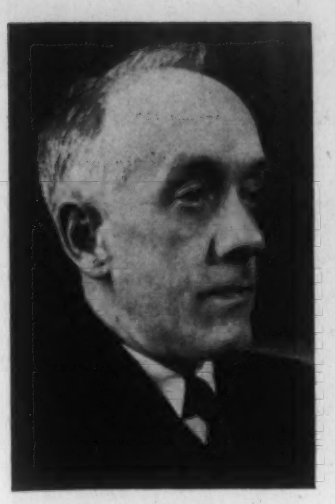


Editorial Comment

Time and Tide

THERE are old saws and wise sayings to the effect that time and tide wait for no man. Neither can we hurry up the tide. Nature is a leisurely old lady who likes to do things just so and at just the rate she has a mind to.

When Nature deals with things metallic, she is often so slow that we find difficulty in telling just what she is doing. In corrosion she often lets a protective film build up, through which, if the film is not disturbed, corroding influences penetrate more and more slowly. The actual life of the metal depends on the maintenance of the corroding influence and on the disturbance of the film. No two pieces of metal may be entirely alike, nor subjected to exactly the same corroding and disturbing influences, but no one has any doubt but that, erratic as the results may seem, Nature is doing exactly the same thing when the conditions are the same. Man may change the conditions, but he cannot change what happens under those conditions. All he can do is find out what the action will be under given conditions and then alter the condition of the metal and of the environment accordingly.

But if he tries to find out what happens and is in too much of a hurry to impose the conditions he really wants to know about and instead uses some other conditions, Nature answers the question he really asks rather than the one he really wishes answered. So when he makes an "accelerated corrosion test," truthful old Nature tells him only what occurs under those exaggerated conditions and reserves the answer to the real question for some one who asks it in the proper way.

When an alloy is subjected to repeated stress, Nature decrees that certain slow changes take place, some tending to improve its resistance, others tending to damage it. The rates at which these changes occur are greatly affected by the magnitude of the stress. In some alloys and at some stresses it takes many millions or even billions of stress cycles before we can tell which of the opposing tendencies will predominate and lead to immunity from further damage or to ultimate failure.

Under long continued static load at elevated temperatures, metals deform minutely, so slowly that we call it "creep," at rates that vary vastly with slight changes in composition and structure of the alloy, in load, or in temperature, and which rates may alter in one direction or the other with time, depending on conditions. Nowhere does Nature treat the metallurgist with more exasperating slowness than in this matter of creep.

In phenomena of diffusion, of precipitation and agglomeration of particles in precipitation hardening processes, in tempering after quenching, in spheroidization and so on, Nature is hasty or leisurely depending on the solubility relations and on the temperature concerned. Some times we get reconciled to the facts and definitely orient our minds to the acceptance of them. We do not expect hardened steel to soften at room temperature within a few thousand years. When we wish to soften it more rapidly, we raise the temperature. Even at elevated temperatures we do not expect spheroidization of cementite to go on instantaneously, we know we have to give it time.

If we really know what different phenomena are taking place, and are able to measure their rates, it is possible to predict what Nature will do and when she will have reached a given point in her fixed but leisurely processes. Since Nature is consistent, if we can find out what she is doing according to her own laws, we can extrapolate by means of those laws. But we have to know *all* the laws.

The astronomer, by recognizing the mutual effects of all the stars and planets on each other, as a result of centuries of observation, measurement and calculation, can devise machines that operate according to those laws and hence in the Adler Planetarium at Chicago, we can see what the positions of the heavenly bodies will be at any future date and know that the extrapolation is accurate, so accurate that an eclipse can be predicted within a few seconds. As a result of this astronomical knowledge the tides can also be predicted and tide computing machines built that will tell the time and height of the tide at any location and any time.

But when one does not know the laws that operate, no such extrapolation can be made. We have as yet no long range weather predicting machine on which you can turn a crank and get the answer to what the weather is going to be at any given place and time.

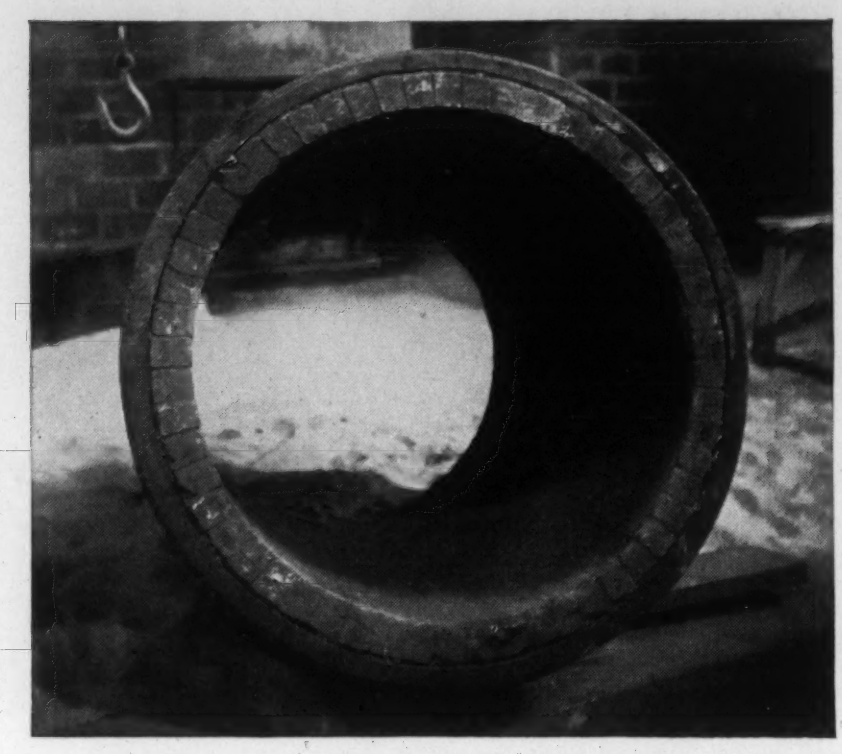
We are slowly recognizing this general situation in metallurgy. Intelligent metallurgists no longer look to drastic accelerated corrosion tests to give a true answer to a corrosion problem of the type in which corrosion slows down with time. They are more likely to inquire whether the test has been so devised that the corrosion products are of the sort and with the degree of adherence of those that are produced in natural corrosion. If so, they may draw some conclusions from the test as to the relative effect of changes they have made in the alloy. But they are not trying to use so accelerated a test that the real tendencies are obscured; they are being more willing to put their questions to Nature in such form that she may answer them.

In fatigue problems, we are seeking for evidences of the type of change being produced and are finding that if we give Nature time enough to develop clear proof of the change, we can come pretty close to telling what her final answer will be. Forced and unreal "accelerated" fatigue tests are already pretty thoroughly abandoned.

But in the creep field, we are still impatient and unwilling to give Nature time to tell her own story in her own way. One engineer who needs to design against creep

(Continued on Page 166)

SIXTY HEATS AS AGAINST TWO



As an evidence of the logic of getting the right Refractory in the right place

HERE are two photographs that tell an important story—that emphasize the importance of the proper selection of refractories.

On the left a furnace shell lined with "Carbofrax"—The Carborundum Brand Silicon Carbide Refractory after *sixty heats.*

Note the condition of the "Carbofrax" Brick—little or no erosion—negative spalling and cracking—the lining still good for further operation.

On the right a shell lined with fire clay brick after *two heats.* In some places the brick has eroded and melted down to the shell—the lining has practically disappeared.

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High-Chromium Iron Alloys for Castings

by W. F. Furman*

The past two decades have been notable for the number of alloy steels and irons which have been developed during the period. In 1913 Mr. Harry Brearley took the first step in the development of stainless (chromium) steel. Since that time progress in the field has been rapid. Each year brings the introduction of some new combination of alloying elements, usually chromium and nickel but including also tungsten, manganese, titanium, molybdenum, etc. It is no wonder that even metallurgists find it difficult to keep in touch with all the developments in the field and that alloys are brought out as something new which may have already had a considerable commercial use in some other part of the world.

Cast chrome irons, containing over 20% chromium, are a case in point. Such castings were first put on the market in this country about 1918 and went through an extended development period before that date. In spite of this, similar alloys are being brought out in Europe as though they were a new development. This confusion is undoubtedly due to the fact that not much in printed form has been available, applicable particularly to these high chrome-iron castings. In this article it is proposed to remedy this and to describe and define, as exactly as possible, castings containing over 20% chromium, with varying carbons and without other alloying elements except in comparatively small quantities.

On April 10, 1916, Dr. F. M. Becket, Vice-President of the Electro Metallurgical Company, filed an application for a patent which was granted on November 6, 1917. (1,245,552) This patent covered an alloy containing chromium 20.00 to 35.00%, carbon 1.50% to 3.00%, silicon 0.00 to 3.00%, the balance being principally iron. While there had been previous patents issued (Brearley 1,197,256, Sept. 5, 1916, and Haynes 1,299,404 issued April 1, 1919, but filed March 12, 1915) which covered chrome-irons in the lower carbon ranges, Dr. Becket's patent was distinctly applicable to castings and much of his previous development work had been with cast materials. Although there had been some scattered production before, manufacture of high chrome-iron castings in commercial quantities started about 1922. A company was organized at that time to produce castings under Dr. Becket's patent and the first castings were made with his active co-operation. Since that time a considerable tonnage of such castings has been turned out each year.

*Vice-President, The Duraloy Co.

THE REDISCOVERY in one country of the useful properties of an alloy previously studied and put into commercial use in another, is not an uncommon matter. As the author points out, the 1 to 3% carbon, 34% chromium cast alloys, "Nirostaguss," whose present situation in Germany was described in the February, 1933, issue of Metals & Alloys, pages 13-17, have had long prior commercial development in the U.S.A.

Indeed, the properties of alloys with up to 3% carbon and 28% chromium were quite completely described by MacQuigg† ten years ago, on the basis of several years of research and commercial use.

†C. E. MacQuigg. Some Commercial Alloys of Iron, Chromium and Carbon in the Higher Chromium Ranges. *Transactions American Institute of Mining Engineers,* Vol. 69, 1923, pages 831-847.

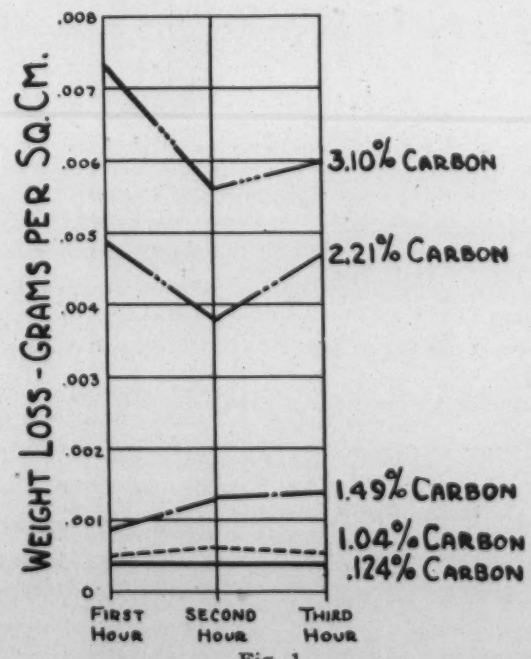


Fig. 1

The metallurgical characteristics of chromium-iron alloys are well known and no attempt will be made here to go over this familiar ground. It should be remembered, however, that much of the literature on this subject has particular reference to forged or rolled materials, usually with low carbons, and does not necessarily apply to castings, there being some essential differences. In forged products the grains will be fairly uniform but this is not true of castings. Here the grain size is usually in direct relation to the rate of cooling so that the cross section has much to do with the grain size. Quick cooling produces a smaller grain. There will be a considerable variation in grain size in the same casting, thin sections perhaps having a fine grain and heavy sections a large, coarse grain. Depending on the carbon, it is sometimes possible to refine the grain by heat treatment, but as a general thing, the grain in the as cast condition cannot be changed.

In general, castings containing over 20% chromium require no heat treatment for maximum corrosion resistance. The usual mormalizing treatment to relieve casting strains, which should be given to all castings, is required. With carbon under about 1.00%, no other heat treatment has much effect. With higher carbons, the case is different. Castings containing say, from 20-35% chromium with carbon over 1.00% are extremely hard in the as cast condition. With carbons around 2.75% they will show as high as 550 Brinell. It is possible to lower this Brinell hardness by the proper heat treatment so that simple machine operations can be performed and the original hard-

ness restored by further heat treatment.

A characteristic which the high chromium-iron castings have in common with rolled products of the same composition is the tendency to become brittle if passed slowly through a temperature range between about 800° to 1000° F. For example, a casting containing about 30.00% chromium, 0.50% carbon, heated to 1200° F. and then cooled very slowly, would become brittle. This brittleness would disappear when the casting was again brought up to temperature, so that, while it was in operation, it would have considerable strength. From the practical standpoint, the disadvantage of this is that castings have to be handled very carefully, when cold, if they have been subject to this embrittling range; that is, have been brought through it slowly.

An advantage which the high chrome-iron castings have over chrome-nickel castings containing around 18.00% chromium, 8.00% nickel, is that they are much less susceptible to intergranular corrosion. The writer has yet to see a chrome-iron casting which has failed for this reason. An interesting example of this was recently observed. Pump impellers containing about 30% chromium, about 0.50% carbon were put in service in an anthracite coal mine where the water was extremely acid. With them were put 2 impellers of the same design but of an alloy with about 24.00% chromium, 12.00% nickel, and 0.50% carbon. These impellers were in service about 3 years. At the end of that time none of them showed any outward signs of corrosion, in fact, the original tool marks could still be seen. It was found, however, that the chrome-nickel impellers had lost almost all the characteristics of metal and that they could be broken into pieces by light hammer blows. A further examination disclosed that the grain boundaries were almost entirely destroyed. All the familiar evidences of intergranular corrosion were present, although these castings had never been operated at higher than room temperature. The straight chrome-iron impellers were not affected and were put back in service.

While it is a little soon to talk of standardization, several distinct types of chrome-iron castings have been developed. Those containing 4.00-6.00% chromium are finding a large use, particularly in the oil fields for header boxes, return bends, and condenser and heat exchanger tubes. Another chromium range is from 12.00-14.00%. Castings in this range can be hardened by quenching and tempered and in general are susceptible to heat treatment. They are used in making valves and also dies and parts subject to abrasion, such as roll guides, glass molds and plungers.

Castings with 16-18% chromium, with carbons not over 0.35% and usually lower were first used commercially because of their resistance to nitric acid and their very satisfactory physical properties. In most of the ammonia oxidation plants built a few years ago 16.00-18.00% chromium castings for pipe fittings, valves, digesters, and such parts were used. These castings will show close to 100,000 lbs./in.^{2} tensile strength, will have good ductility and machine readily. Certain difficulties developed in making them because of a peculiar tendency towards wild heats and consequent blowy castings, but this has been pretty well overcome by foundries specializing in this grade.

In the next class are included all castings containing over 20.00% chromium. This can be divided roughly into 2 subdivisions; viz: castings containing from 20.00-30.00% chromium and those containing over 30.00% chromium.

Most of the castings produced in this country would come in the first subdivision and of these by far the greater percentage has run from 27.00-30.00% chromium. Early in the production history of this grade of castings, the usual chromium range was from 25.00-28.00%, but it was found that there were advantages in having the chromium a little higher which more than offset the slightly increased cost.

Chrome Iron Paddle Casting

The characteristics and uses of 27.00-30.00% chrome-iron castings vary with the carbon content. Characteristic carbon ranges are:

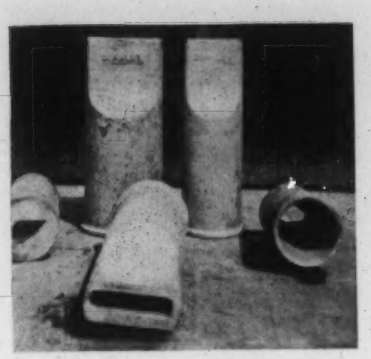
Low Carbon, under 0.30 Carbon
Medium Carbon, about 0.50 Carbon
Medium High Carbon 1.00 to 1.50% Carbon
High Carbon, about 2.75% Carbon

It is generally understood that in alloy castings corrosion resistance decreases as the carbon content increases. Thus for maximum corrosion resistance, low carbons are necessary. However, only the carbon which is not in solution is detrimental to corrosion resistance. Since a given amount of chromium is required to satisfy a definite quantity of carbon through the formation of chromium carbides, any given carbon content will, therefore, rob the iron-chromium solid solution of some of its corrosion-resisting chromium. Increasing the chromium, with carbon constant, will leave more chromium available for enriching the iron-chromium solid solution, thus increasing corrosion resistance. Thus a 27.00-30.00% chrome-iron with, say, 0.20% carbon is much more resistant to corroding media than a 12.00-14.00% chrome-iron with the same percentage of carbon present. Practically, this means that higher carbons can be used safely in the 27.00-30.00% chrome iron castings. This is an advantage from the foundry standpoint; the higher carbon melts are more liquid, flow more freely and produce a smaller, denser grain. Melting and molding costs are reduced. Also from the standpoint of corrosion resistance, a small grain is in itself an advantage.

Castings containing about 28.00% chromium and under 0.10% carbon are now being produced, where maximum corrosion resistance is essential. In the writer's opinion, it is not really necessary to run the carbon as low as this, when the chromium content is close to 30.00%. Practically as good corrosion resistance to most media can be secured with carbons as high as 0.25% and as a rule, a sounder grade of castings results. Perhaps a safe rule is to keep the carbon not over 1/100th of the chromium content and even this is too severe a restriction for many applications.

In these high chromium castings, increasing the carbon content has almost no effect on the oxidation resistance. A 27.00-30.00% chrome iron casting will resist oxidation in an oxidizing atmosphere very satisfactorily at temperatures up to about 1900° F. and satisfactorily for most purposes up to about 2100° F. This remains true, even if carbons run as high as 3.00%, although castings with the higher carbons would show more tendency to crack at these high temperatures.

Therefore, the field for the low carbon casting is mostly for corrosion resistance and it is probably true that as operating requirements become more severe, many users are going to insist on these low carbon castings for many applications.



Chrome Iron Roll Guides

Castings with carbon about 0.50% comprise the great bulk of the tonnage produced. Such castings have a very satisfactory resistance to most corroding media and are excellent for high temperature applications where the greater strength which the nickel-chrome alloys have, is not a requisite. Because of the higher carbon, they have a denser grain than the low carbon castings already mentioned and slightly greater physical strength, though also slightly less ductility. They machine readily, being comparable to medium carbon steel in this respect.

Castings of this type are almost completely resistant to the acid water found in many coal mines. These waters contain H_2SO_4 and other acids and oxides and are extremely corrosive. In 1922, Bulletin 4, Coal Mining Investigations, was published by Carnegie Institute of Technology, which reported investigations made by Messrs. Selvig and Enos on the resistance of various metals and alloys to these acid mine waters. A chrome-iron containing 29.50% chromium and 0.36% carbon showed no visible corrosion in contact with any of the waters used in these tests. About this time, the commercial production of a similar alloy was begun and castings of it were almost immediately put in service in various mines, mostly for pump parts. Since then, many all chrome-iron pumps have been installed and chrome-iron impellers and wearing parts used with bronze casings. The results have been extremely satisfactory. Pump parts in service for some years have been examined, showing no apparent corrosion.

Another use for such castings is for nitric acid or mixed nitric and sulphuric acid resistance. About 0.50% carbon is very satisfactory for such work. Castings containing 28.20% chromium, 0.49% carbon were tested against a 50.00% nitric acid solution and also against a mixed acid, containing 33.40% nitric, 42.40% sulphuric and 24.20% water. Both solutions were boiling and test samples were immersed for 24 hour periods. Three tests gave the following results:

	1st Test	2nd Test	3rd Test
Nitric	.019	.012	.010
Mixed Acid	.37	.35	.35

The results are in terms of inches penetration per year.

It is of course realized that a 24-hour laboratory test is not conclusive. The above test is merely indicative but its results have been confirmed by a great number of actual installations, some of them over periods of 6-8 years.

The same composition (28.20% Cr and 0.49% C) was tested against a mixed acid solution in which the nitric and sulphuric were in the same proportion to each other as in the mixture given above but the total acidity was reduced to 0.50%. Samples were immersed in the boiling solution for the periods indicated, removed after each immersion, cleaned, weighed and put back for another period. The results are expressed in weight loss, grams per square inch, but a running total is kept, so that figures after each time period indicate the total loss from the start of the test. This particular test was developed as a practical means of determining whether castings would give satisfactory service under actual operating conditions. Two conditions are required, the first that total weight loss shall not exceed .25% and the second that weight loss cease after a certain number of boils, indicating that castings have become passive. The test follows:

	Weight Loss	
Hours Boil	Test "A"	Test "B"
2	.026	.030
4	.041	.037
8	.044	.039
12	.045	039
16	.047	.042
20	.048	.042

In service, these castings have given excellent results as valves, pipe fittings, paddles, screen frames, manifolds, digesters, and various other parts in contact with nitric acid or a weak mixed nitric acid and sulphuric acid. Castings containing over 27.00% chromium are very resistant to the bright dip solution (usually mixed nitric, sulphuric and hydrochloric acids) found in brass manufacturing plants and to the various copper sulphate solutions.

Castings of this composition are used at elevated temperatures because of their remarkable resistance to oxidation and to sulphur fumes. While they will show a much greater strength at high temperatures than ordinary iron or steel, they do not compare favorably in this respect with alloys containing appreciable amounts of nickel. They also tend to show grain growth at high temperatures and are somewhat susceptible to cracking when subjected to frequent heating and cooling, particularly if water quenched when very hot. But in spite of these disadvantages, they are being used successfully for many high temperature applications, particularly where the presence of sulphur gases makes the use of a nickel alloy dangerous. Rabble arms and blades in ore roasting furnaces are being made of this grade of chrome-iron castings with excellent success. One company reports that such arms have lasted 4½ years in a furnace roasting zinc ore and are still in good condition. Cast iron arms under the same conditions last from 3 months to 1 year. The 27 to 30% chrome-iron castings, with or without small nickel additions have been used for making retorts for calcining lithopone, operating temperature being about 1800° F. Retorts cast of this alloy have given better results than high nickel-chrome alloys for this service. This particular grade is also used for recuperators through which pass products of combustion, usually high in sulphur, furnace parts where sulphur resistance is important, bisulphide pots, brass melting retorts and many similar applications.

Chrome-iron castings containing from 1.00-1.50% carbon have not been produced extensively but do meet certain special requirements. Because of the high carbon, corrosion resistance is decreased. Castings will often show a brown rust film when exposed to ordinary atmospheric conditions. In spite of this, there is still left a considerable amount of corrosion resistance and with it, because of the higher carbon, a much greater abrasion resistance. Such castings have been used for making sand pumps, where the water is mildly corrosive and good abrasion resistance a requisite. With the present tungsten carbide tools, simple machining operations can be performed on them so that their use for pump parts is practical.

Castings containing approximately 2.75% carbon form a very distinct group. This particular carbon produces a fine, dense grain and increases the physical strength but lowers ductility so that castings are rather brittle. Since castings are susceptible to heat treatment, it is possigle to soften them so that simple machining operations can be performed subsequently, bringing them back to their original hardness. Even as cast, they will show, depending somewhat on the section and the time required for cooling, Brinell hardness numbers running from 400 to 500 and they can be made harder by proper heat treatment.

Tests were run from a typical heat of this grade, the analysis being as follows:

Chromium	27.60%
Carbon	2.30%
Silicon	3.00%
Manganese	1.15%
Nickel	1.38%

As cast, test bars showed a Rockwell value of 50 on the C scale and a Brinell number of 444. In a transverse break test, bar broke under a load of 6800 lbs. with a deflection of 0.128". In the as cast condition they were not machinable. Long soaks at temperatures around 1400° F. and furnace cooling softened them so that simple machine operations could be performed without great difficulty. Heated at 2000° F. for 4 hours and water quenched, castings showed a Rockwell value of 53 on the C scale and Brinell number of 512.

Castings of this type will have considerable resistance to corrosion although naturally much inferior in this respect to the lower carbon castings in the 20.00-30.00% chromium group. Oxidation resistance is not affected by the higher carbon, but their inherent brittleness and a tendency to crack when subjected to high temperatures makes their use undesirable for high temperature conditions, except for very special applications.

For abrasion resistance, these castings show very satisfactory results. This is particularly true when some resistance to corrosion is also essential but is also true where abrasion resistance alone is to be considered. They have been used for crusher and liner plates, extruding dies, roll guides, grizzlies and grinding rolls with sufficient success to justify their increased cost over chilled iron or manganese steel.

The chromium content gives them an inherent toughness so that their resistance to abrasion is greater than an iron of the same Brinell hardness. Because of their low ductility they cannot be used if subjected to any great amount of shock.

The next general group of castings includes those with a chromium content over 30.00%. In the February 1933 issue of *Metals & Alloys* appeared a paper by E. Houdremont and R. Wasmuht, entitled "Non-Rusting & Heat Resisting 34% Chromium Alloy Cast Iron." As the title indicated, this paper described alloy castings containing around 34.00% chromium, with carbon varying mainly between 1.00 and 3.00%. From this article it would be assumed that this particular alloy was an entirely new development. Such is not the case as similar alloys have been produced commercially in this country for at least the past 10 years and experimentally for a much longer period. Their use has not been extensive as they possess certain limitations, although it has been understood that for some special purposes keeping the chromium over 30.00% is an advantage. Increasing the chromium gives a slightly greater resistance to oxidation, although the proportionate increase after about 22.00% chromium is small. A slight increase in corrosion resistance can also be expected, although practically this is not very important.

The paper in *Metals & Alloys* makes claims for superior corrosion resistance of 34.00% chromium, 1.00-3.00% carbon castings, which cannot be substantiated by results obtained from a similar alloy under actual service conditions in this country. It would be expected that the same ratio between carbon content and corrosion resistance would apply to such castings as to the lower chromium grades and actual test and installations bear this out.

For example, in tests run January 10, 1923, at the Union Carbide and Carbon Research Laboratory, to determine the resistance of such an alloy to phosphoric acid, 3 different carbons were used. Test bars analyzed as follows:

	Carbon	Chomium	Silicon
Alloy A	1.65	32.16	.30
Alloy B	1.91	41.08	.32
Alloy C	.48	33.97	.67

Castings were immersed in various concentrations of acid at various temperatures for period of 24 hours. The results are shown in Table 1.

Table I.

Strength Acid (Phosphoric)	Temperature °F.	Time Hours	% Loss in Weight A	B	C
85%	Room	24	Nil	Nil	Nil
85%	212°	24	.22	.2	.13
50%	Room	24	Nil	Nil	Nil
50%	212°	12	.03	.04	Nil
50% to Conc.	212-284°	24	5.69	1.09	.84

Another more recent test is shown in Table 2. Samples were taken from heats running over 30.00% chromium with varying carbons. In sample A manganese ran .86% and silicon .54%, the balance being iron. In other samples, manganese and silicon were almost the same as in Sample A. The test consisted of immersing polished samples for hourly periods in the boiling mixed acid described. After each hour samples were removed, cleaned thoroughly, dried and put back in the boiling solution.

Table II—Analysis.

	SAMPLES A	B	C	D	E
Chromium	34.40%	33.00	32.84	32.72	31.67
Carbon	0.124%	1.04	1.49	2.21	3.10

WEIGHT LOSS
In grams per square centimeter per hour.

	A	B	C	D	E
1st hr.	.00045	.00052	.00091	.0049	.00735
2nd hr.	.00043	.000625	.00136	.0038	.0056
3rd hr.	.000423	.000545	.00142	.00475	.0060

Test consisted of immersing samples in boiling solution, consisting of:—
33.00% HNO_3, 42.00% H_2SO_4, 24.00% H_2O

From the Table 2 and Fig. 1 the effect of carbon on corrosion resistance, even in the very high chromium alloys, can be clearly seen. Each increase in carbon lowers the corrosion resistance. Increasing the chromium tends to offset this, as indicated in Table 1 but not to the same extent. Practically, the indicated range of carbon to chromium as 1:100 is a safe rule to follow, no matter how high the chromium runs, if maximum corrosion resistance is required. There is nothing particularly to be gained, except in unusual cases, in running chromium over 30.00% for most corrosion applications. It is still necessary to hold carbons low and this can be done in the 27.00-30.00% chromium range which is more or less standard in this country.

For this reason, the use of castings containing around 34.00% chromium, over 1.00% carbon does not seem advisable for most corrosion applications. Such castings, compared with castings containing close to 30.00% chromium and about 0.50% carbon will show very much less corrosion resistance, much less machinability, more brittleness and the cost advantage will be slight. While they have a place as indicated by their use in this country for a number of years, it hardly seems that this place is as extensive as would be assumed from the claims made in the paper referred to above.

For a time claims were made that an alloy containing over 40.00% chromium was resistant to molten zinc. Several heats of this alloy were made but actual results did not substantiate these claims. Resistance to molten zinc was slightly increased but not sufficiently to justify the use of so expensive a material.

Heats have also been made of alloys containing as much as 50.00% chromium. Satisfactory castings can be made from this alloy, which are not excessively brittle and can be machined. As would be assumed, such castings show a very marked resistance to oxidation and may find some use for particularly severe applications although so far their use has been limited.

(Continued in November issue)

Residual Metals

in

Open-Hearth Steel

by Clyde E. Williams* and John D. Sullivan*

IN A PREVIOUS article[1] we discussed residual metals in open-hearth steel and presented analyses of samples from 18 steel companies in the United States and Canada for the periods March-July 1931 and August 1931-January 1932. As was stated in the former article, samples are taken from representative heats before alloy additions are made. At the end of the month, composite samples of these are made and sent to Battelle Memorial Institute. Here, quarterly, semi-annual, or annual composites are made for analysis. The collection of samples and making of analyses go on from year to year. This report brings the results up to date.

In Table I results are reported from March 1931 to January 1933, inclusive. Two plants of the previous period (August 1931-January 1932) are not represented in the current period (February 1932-January 1933). Three new plants are added. A normal annual tonnage capacity of 6,300,000 tons is represented by the 19 plants coöperating in the current period.

Fig. 1 shows graphically the average percentage of residual metals from all plants for December 1929 to January 1933, inclusive. Results are given for the arithmetic mean of all plants and also for the weighted average based on normal annual tonnage capacity. In Fig. 2 results are given for the 10 plants that have coöperated in all periods since this investigation started. In the figures the year is plotted as the middle of the period represented. Analyses reported in Figs. 1 and 2 were made at the Pittsburgh Station of the U. S. Bureau of Mines until March, 1931, and at Battelle Memorial Institute since that time.

Since our former paper showed that the amounts of arsenic, lead, molybdenum, vanadium, and zinc present as residual metals were 0.001% or less, analyses were not made for these elements during the last period.

The average of all plants, by tonnage capacity, shows an increase over the previous period for all constituents except manganese. The average, by plants, shows an increase for chromium and nickel, a decrease for manganese and copper, with tin remaining constant.

The average, by tonnage capacity, of the 10 plants that have coöperated in all 6 periods shows an increase over the previous period for all constituents. In the same 10 plants the average, by plants, increased for chromium and nickel, decreased for manganese and copper, and remained constant for tin. In the former paper curves, including 1931, were given to show the variation in the amount of steel scrap used in different years and to permit comparison of this with prices and production rates. In the present paper these curves have been extended for the year 1932. Figures for scrap consumption were obtained by calculation from the statements of basic pig iron and basic open-hearth steel production contained in the Annual Statistical

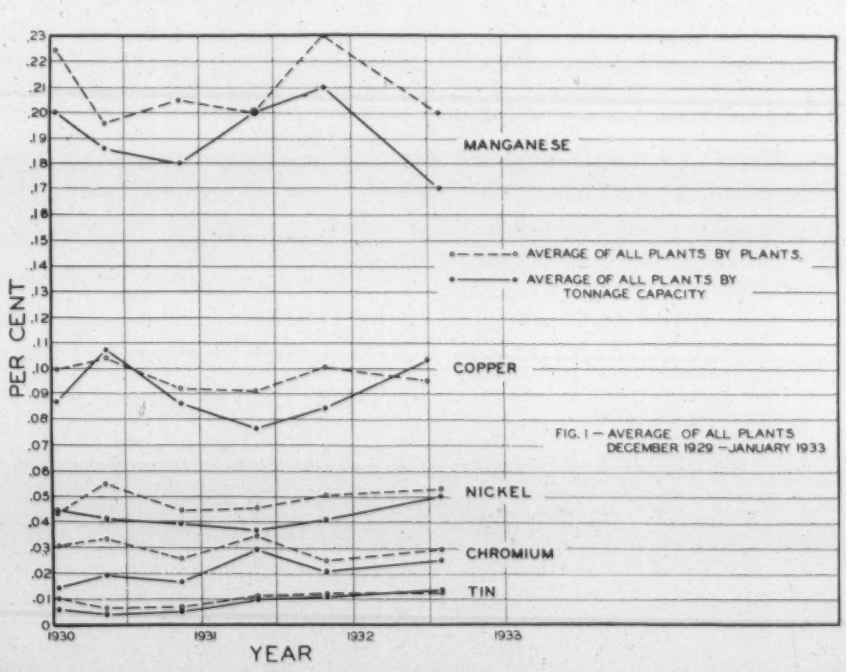
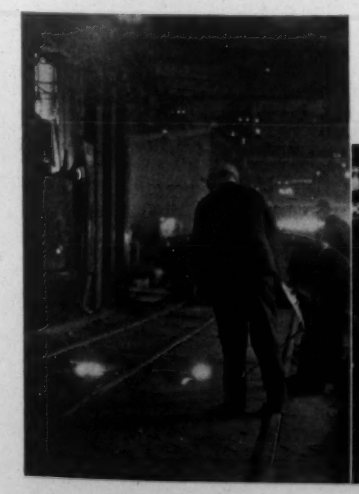
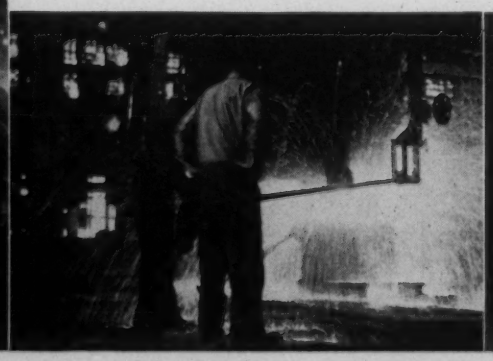


Fig. 1



Pouring a Sample for the Laboratory.



Pouring a 108" Ingot for a Single Forging.

Fixing the Tap Hole After The Tap.

Running Off the Slag.

(Courtesy The Midvale Company)

*Battelle Memorial Institute, Columbus, Ohio.

[1]Clyde E. Williams & John D. Sullivan. Residual Metals in Open-Hearth Steel. *Metals & Alloys*, Vol. 3, 1932, page 240.

TABLE I. RESIDUAL METALS IN OPEN-HEARTH STEEL

March 1931—January 1933, inclusive

Plant No.	% Ni			% Cu			% Sn			% Mn			% Cr		
	1931 Mar.-July	1931-32 Aug.-Jan.	1932-33 Feb.-Jan.	1931 Mar.-July	1931-32 Aug.-Jan.	1932-33 Feb.-Jan.	1931 Mar.-July	1931-32 Aug.-Jan.	1932-33 Feb.-Jan.	1931 Mar.-July	1931-32 Aug.-Jan.	1932-33 Feb.-Jan.	1931 Mar.-July	1931-32 Aug.-Jan.	1932-33 Feb.-Jan.
A	0.039	0.063	0.109	0.025	0.045	0.051	0.004	0.003	0.004	0.22	0.24	0.23	0.048	0.031	0.040
C	0.043	0.054	0.054	0.097	0.215	0.218	0.017	0.025	0.034	0.11	0.11	0.10	0.020	0.019	0.028
E	0.089	0.071	0.055	0.268	0.296	0.193	0.035	0.041	0.021	0.11	0.24	0.12	0.052	0.036	0.033
F	0.032	0.072	0.057	0.106	0.080	0.080	0.014	0.013	0.014	0.15	0.16	0.14	0.031	0.026	0.029
G	0.041	0.037	0.037	0.030	0.015	0.015	Nil	0.003	0.005	0.35	0.46	0.42	0.044	0.038	0.040
H	0.071	0.060	0.062	0.075	0.077	0.097	0.011	0.017	0.012	0.12	0.11	0.10	0.029	0.030	0.028
I	0.008	0.030	0.027	0.059	0.074	0.069	0.008	0.006	0.005	0.10	0.08	0.06	0.012	0.012	0.013
J	0.021	0.038	0.041	0.049	0.062	0.050	0.003	0.006	0.006	0.27	0.48	0.22	0.021	0.021	0.021
K	0.019	0.031	0.049	0.076	0.084	0.120	0.008	0.012	0.014	0.12	0.13	0.14	0.025	0.011	0.025
L	0.053	0.039	0.048	0.075	0.077	0.083	0.007	0.006	0.013	0.26	0.24	0.27	0.033	0.022	0.027
M	0.039	0.034	0.042	0.117	0.085	0.098	0.008	0.009	0.010	0.25	0.24	0.20	0.023	0.006	0.010
N	0.041	0.040	0.043	0.065	0.113	0.085	0.008	0.008	0.011	0.16	0.16	0.14	0.034	0.031	0.034
O	0.063	0.083	0.068	0.202	0.215	0.182	0.020	0.017	0.018	0.19	0.18	0.18	0.049	0.036	0.041
P	0.082	0.107	0.087	0.088	0.138	0.122	0.009	0.015	0.017	0.24	0.24	0.23	0.049	0.030	0.038
Q	0.057	0.050	0.047	0.122	0.114	0.116	0.021	0.022	0.018	0.25	0.23	0.21	0.049	0.046	0.045
R	0.063	0.044	0.060	0.040	0.032	0.061	0.005	0.004	0.008	0.26	0.31	0.30	0.021	0.021	0.023
S	—	—	0.039	—	—	0.056	—	—	0.007	—	—	0.32	—	—	0.030
T	—	—	0.036	—	—	0.054	—	—	0.006	—	—	0.28	—	—	0.028
U	—	—	0.040	—	—	0.058	—	—	0.007	—	—	0.07	—	—	0.022

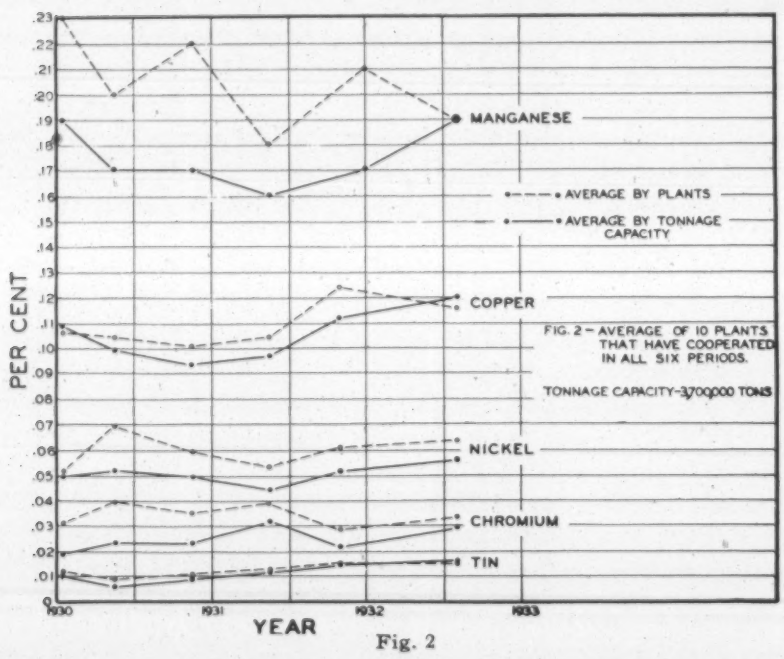


Fig. 2

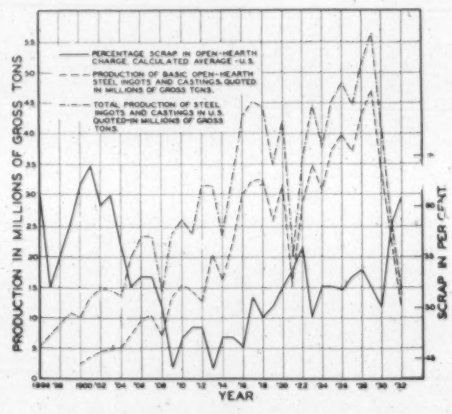

PRODUCTION IN MILLIONS OF GROSS TONS
SCRAP IN PER CENT
YEAR
PERCENTAGE SCRAP IN OPEN-HEARTH CHARGE, CALCULATED AVERAGE – U.S.
PRODUCTION OF BASIC OPEN-HEARTH STEEL INGOTS AND CASTINGS, QUOTED IN MILLIONS OF GROSS TONS.
TOTAL PRODUCTION OF STEEL INGOTS AND CASTINGS IN U.S. QUOTED IN MILLIONS OF GROSS TONS.

Fig. 3. Relation Between Amount of Scrap Used in Basic Open-Hearth and Production of Basic Open-Hearth and Total Steel.

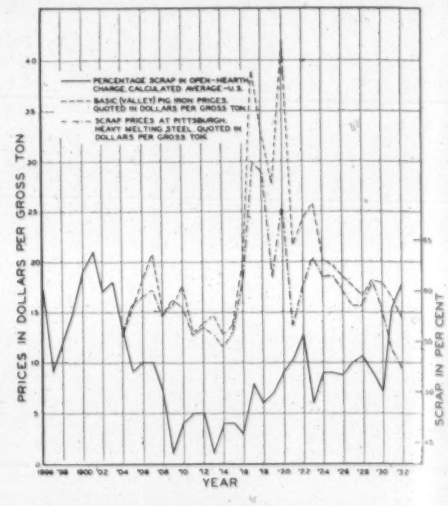

PRICES IN DOLLARS PER GROSS TON
SCRAP IN PER CENT
YEAR
PERCENTAGE SCRAP IN OPEN-HEARTH CHARGE, CALCULATED AVERAGE – U.S.
BASIC (VALLEY) PIG IRON PRICES QUOTED IN DOLLARS PER GROSS TON.
SCRAP PRICES AT PITTSBURGH, HEAVY MELTING STEEL, QUOTED IN DOLLARS PER GROSS TON.

Fig. 4. Relation Between Amount of Scrap Used in Basic Open Hearth and Prices of Basic Pig Iron and Steel Ingots.

Reports of the American Iron and Steel Institute and in Mineral Industry. In determining the percentage of scrap used, the following assumptions were made: (1) An ingot recovery of 88% of the metal charged, (2) metallic addition agents equivalent to 1% of the charge added, and (3) iron ore containing 50% of recoverable iron used to the extent of 5% of the pig iron charged.

The figures show that the percentage of scrap used in basic open-hearth steel increased from 59% in 1931 to 61% in 1932.

The study of residual metals in open-hearth steels will be continued over a long enough period to establish the trend and to determine the rate at which the amounts of the various residual elements are changing.

Charging Side of Open Hearth Furnaces at Bethlehem Plant. (Courtesy Bethlehem Steel Company)

The Tapping Side of the Open Hearth Furnaces. (Courtesy Youngstown Sheet & Tube Company)

Characteristics of Some Fuel Fired Furnace

CONTROL SYSTEMS

by R. A. Smart*

IN the three months since the passage of the Recovery Act on June 14, tonnage has gone up considerably and superintendents have been faced by a serious shortage of furnace control *men*. Hence the increasing adoption of automatic controllers. The author discusses the characteristics of electro-mechanical valve-operating units which he terms "controllers." According to Behar's Manual of Instrumentation an automatic controller consists essentially of a measuring system commanding a motorized valve or other power unit. A valve-operating unit, by itself, is not automatic and therefore is not a temperature controller. Some engineers go so far the other way as to restrict the use of the term "controller" to the control instrument. This, too, is incorrect, as both elements are essential to a complete control system. It seems to *Metals & Alloys* that the terminology of Instrumentation should be adopted by metallurgical engineers.

"Since the temperatures encountered in most fuel fired furnaces are comparatively high, this discussion will be confined to control systems employing instruments of the thermoelectric type and to control valves of the motor-operated type. In general, the control system will consist of the following elements: A thermocouple (see Fig. 1), with its indicating or recording pyrometer, the latter fitted with suitable electrical contacts for opening and closing circuits at designated high and low temperatures, these circuits frequently actuating a relay, to operate a motor-driven device, herein termed the "controller" which is mechanically connected to one or more fuel and air valves or dampers.

In his comprehensive article on temperature control[1] M. F. Béhar said "A thermometer or pyrometer indicates what the temperature *is*. A recorder shows what the temperature *was*. An automatic temperature controller deals with the future." To his statement we might add that a pyrometer signals that something has just gone wrong with the temperature and that corrective measures must be taken. The controller must act in response to the signal and decide on the nature and extent of these corrective measures. This discussion will be confined to the design and functioning of the controller with its attached valves, since, in the last analysis, they will be largely responsible for the success of the system.

Three characteristics of furnace performance are affected by the system of control selected and by the design of its mechanical and electrical elements. The first is the maintenance of a uniform temperature. This frequently is the sole reason why a control system is installed, but the system selected will have an effect on (2) the atmosphere within the furnace, and also upon (3) its fuel economy.

Control of Temperature—Manual Operation

It can be stated as a basis for discussion that the best obtainable control of temperature is manual control, provided that the operator be skilled, that he be on the job continuously with nothing to divert his attention and that he be provided with an accurate temperature measuring instrument—preferably a recording pyrometer—and with suitable hand valves. Such a man, watching the pyrometer chart minute by minute, noting the tendencies to deviation almost before they occur, and aware of proposed changes in loading before they occur, is in a position to check or correct temperature deviation with a minimum loss of time and with a maximum of judgment as to the probable fuel change required. And here we must remember 2 things Béhar pointed out: that a furnace which cannot be controlled manually cannot be controlled automatically, and that there are manually controllable jobs which do not lend themselves to automatic control.

Depending on the type of furnace being controlled, our manual operator will have to do a good deal of shrewd guessing if the furnace temperature is to draw a good line on the recorder chart. His chief difficulty is the presence of a lag or time delay, both in the temperature indicating or recording system and in the furnace itself. We shall call the former instrument lag and define it as the time interval between the moment when the temperature surrounding the thermo-couple protecting tube changes and the moment when this change is evident at the indicating or recording point. This lag, the less important of the two, is chiefly a function of the design construction and dimensions of the pyrometric system. The furnace lag is the time interval between the moment when a change has been made in the rate of fuel supply and the moment when the temperature at the thermocouple has been changed correspondingly. Obviously the instrument pointer will come to rest at the new point only after the expiration of a time interval equal to the sum of these 2 lags.

In nearly all control systems there is a third element of delay due to the fact that it is impracticable to change fuel flow at the moment when departure from the holding temperature becomes evident. It usually is necessary to permit a departure of several degrees before corrective action is taken. Our manual operator will probably make no move at the first sign of departure but will wait until there is some evidence of its probable extent and permanency. If now we add this third time delay to the two already described, we arrive at the total lag, *i.e.*, the time interval between one required fuel adjustment and

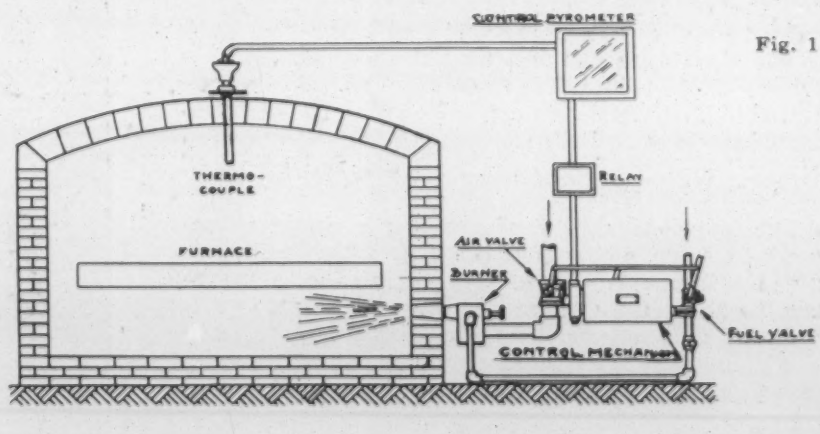
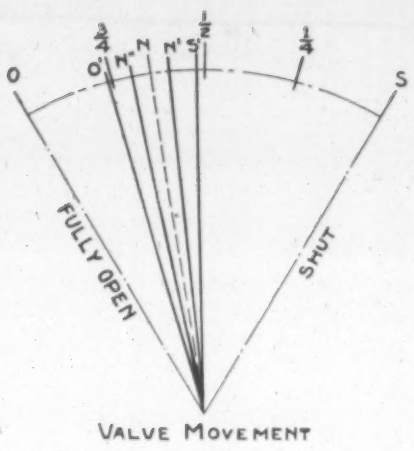


Fig. 1

*Automatic Temperature Control Co., Philadelphia.

[1]*Instruments*, Vol. 3, July 1930, pages 425-462; August 1930, pages 511-528.



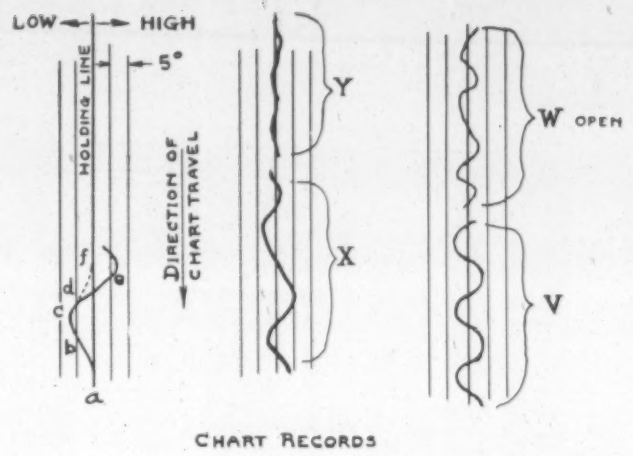


Fig. 2

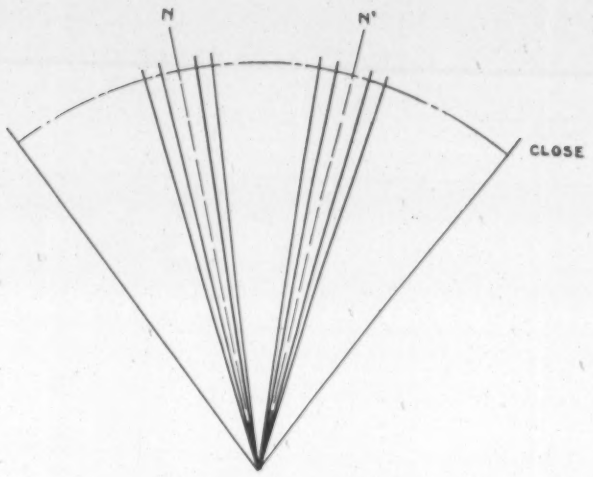


Fig. 3

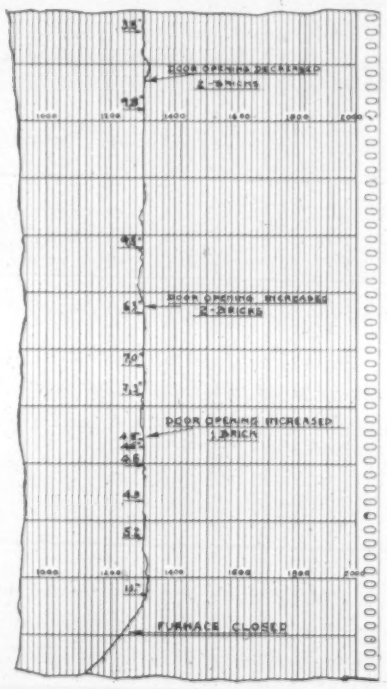


Fig. 4. Balancing Control

Fig. 5

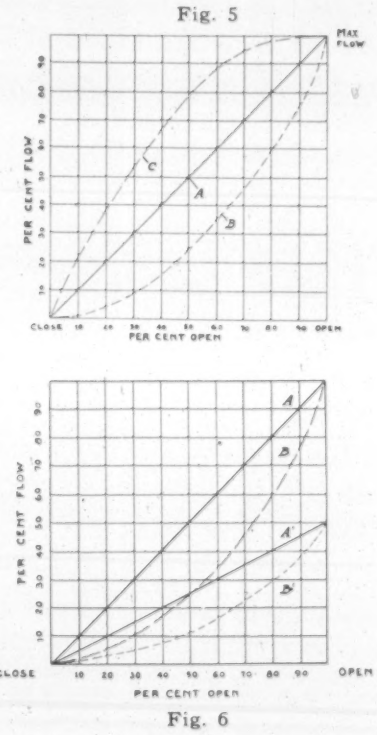


Fig. 6

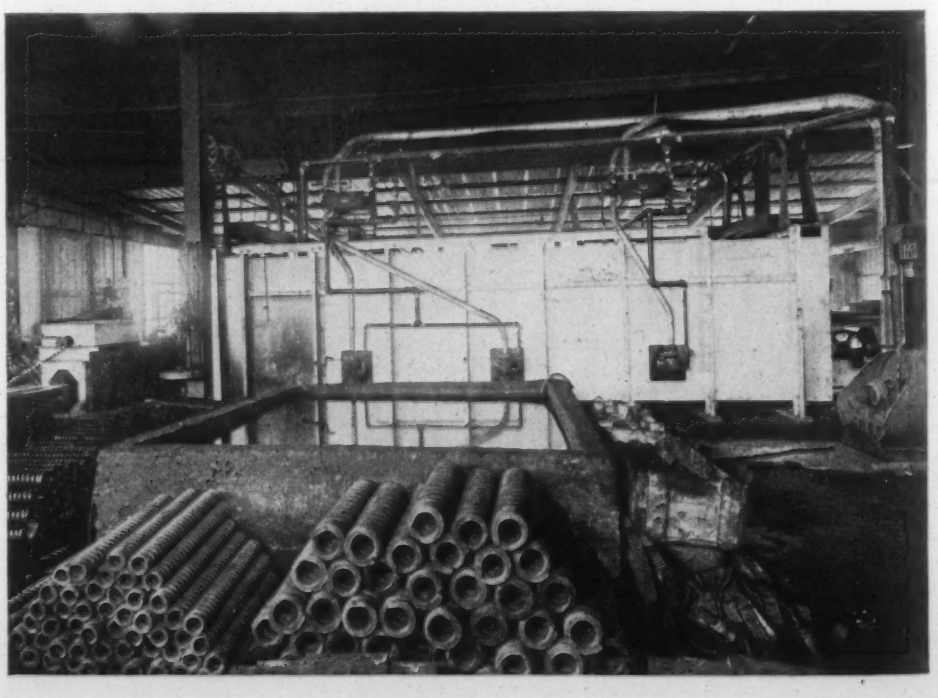
the next, should additional adjustments be required. This total lag may be a matter of seconds or of many minutes, depending on design and construction of furnace, burner and temperature measuring system. The greater the lag, the harder the control problem, in almost geometrical ratio. If there were no lag, there would be no problem.

The word "anticipation" tends to creep into the language of control, but with automatic control, there is no such thing as true anticipation, or preparation *before* the event. The effort at correction must always start *after* the deviation is under way. The word "anticipation" can only be used relatively as applying to some device, the use of which permits action in advance of what is otherwise possible.

Let us suppose now that our manual operator is seated at his fuel valve with the recorder chart in front of him. In order that he may not have an advantage over his automatic counterpart, we will afford him no advance knowledge of changes in loading and we will instruct him to wait until the temperature deviates 5° in either direction before taking any action. In other words, we will handicap him just as the automatic system is handicapped, and will therefore not compare his imperfect methods with those of the ideal manual operator referred to earlier in the article. Suppose now that the line starts to drop, as shown at (a) Fig. 2. (We have purposely drawn this chart with an exaggerated scale for greater clarity.) At the left is shown the arc of a circle representing the movement of the handle of a lever-type fuel valve, from shut to fully open, with the position *N* marking the normal amount of opening required to give the requisite average flow and to maintain the desired holding temperature. At point (b), with the temperature already 5° off the line, our operator must make a good guess as to how far it is likely to go and a further guess as to how far to move the valve to counteract the deviation. Of course, he would like, at once, to open just enough to bring the line back to the starting point and hold it there but, unfortunately, that is not practicable as will be explained shortly. So he moves the valve as his judgment indicates and then must wait for the duration of the lag in order to find out the full effect of this initial movement.

The impracticability of making a single movement to some new valve position which will balance the increased demand, returning the temperature to and holding it at the original point, is evident. By way of analogy, assume 2 automobiles to be traveling along the road at a speed of 40 miles per hour and separated with a space interval which the driver of the following car wishes exactly to maintain. Assume that the leading car speeds up to 50 miles per hour before the following driver is aware of the change. On account of the time lag in his reaction, the following driver will be obliged to exceed 50 miles per hour for a short time in order to regain the original space interval between the cars, but when this is regained, it can be maintained by again matching the speed of the first car. Similarly, our operator could not, even though he knew the exact new valve position that would balance the new fuel demand, move to that position and expect the line to return promptly to and stay at the holding point. By reason of the lags in his moving of the valve and in the temperature response of the furnace to the increased fuel supply, he must first supply an excess of fuel over the new demand rate and then come back to that rate. If not, the return to the holding temperature will not be accomplished.

We will assume that when the line has reached point (b), 5° below the holding point, our operator moves the valve to *O'*, his experience indicating that this new position will probably



Controllers on Gas Fired Hagan Furnace at Pittsburgh Commercial Heat Treating Company.

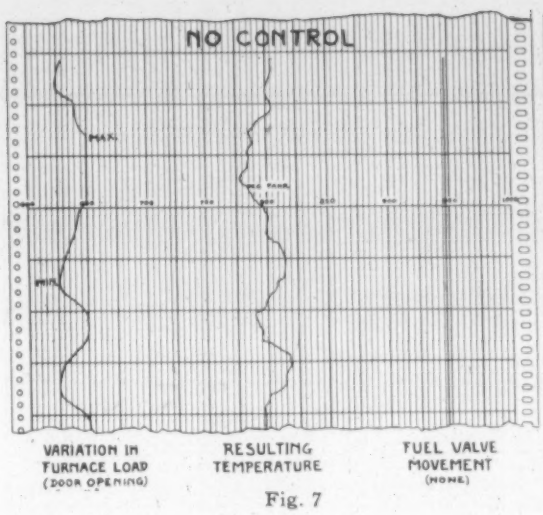


Fig. 7

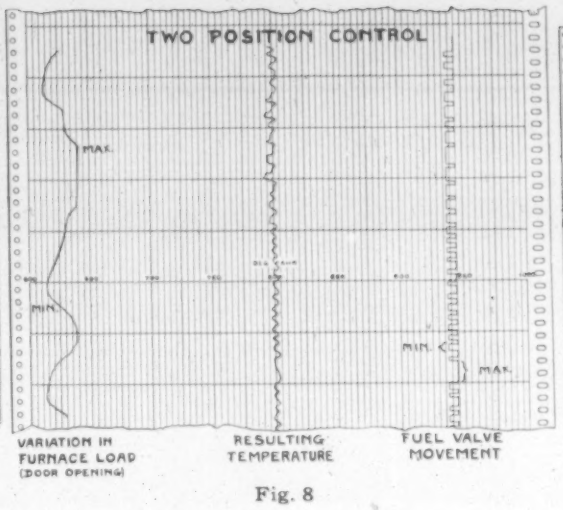


Fig. 8

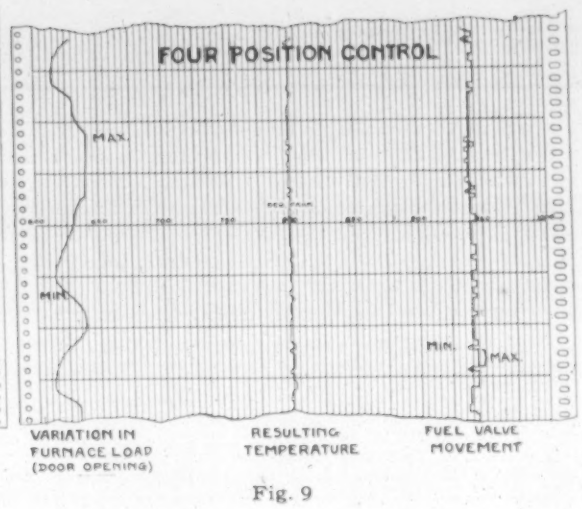
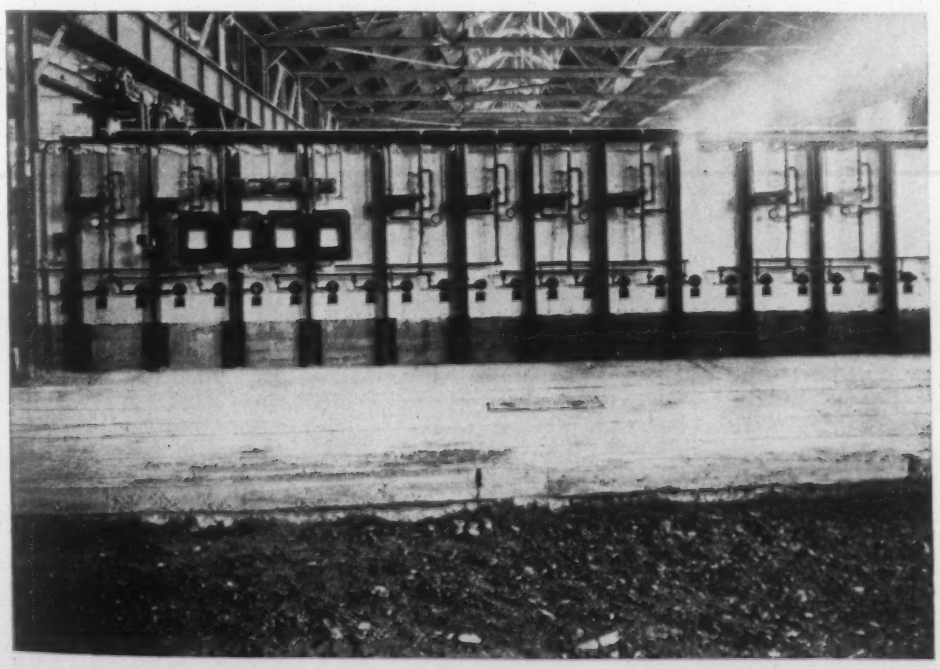


Fig. 9

check the drop. Due again to lag, the line will continue to drop for a short time to point (c) and then turn and start an ascent. However, the operator cannot permit the valve to remain at O' longer than is necessary to restore to the furnace the heat loss occasioned by his failure to open the valve at the precise moment when the increased demand began. Valve position O' is feeding more fuel than is required by the new demand, but this momentary excess supply must be provided or the holding temperature would not be reached again unless the load were reduced.

If the operator should now wait until the temperature reaches the holding point before checking its rise, there will be some overshooting; and if he should wait further until the line reaches point (e), the overshooting will be considerable. This last mentioned procedure is a characteristic of "two-position" systems which have but 2 valve positions and which take no corrective action until after the temperature has crossed the holding point by a certain number of degrees. This method of control will keep the temperature within bounds but inasmuch as the 2 valve positions provided are both chosen with reference to abnormal demands, the result is bound to be coarser control than would be the case if the valve could assume intermediate positions to care for normal demands.

If our operator were content always to close off to a fixed minimum at each rise and to open up to a like maximum at each decline, without attempting to find and hold some intermediate position on which he could rest for a time, we would have to conclude that he was unintelligent. He must keep moving almost continuously, since he stops only on 2 positions, both of which are corrective but neither of which can be right for the prevailing demand. If the result is a temperature that does not hunt too violently for the proper treatment of the work in the furnace, X, Fig. 2, we might not need to seek further refinement of control. But, as will be shown later, this continued hunting may possibly cause some serious effects.



Controllers on Four-Zone Batch Type Normalizing Furnaces at National Tube Company, McKeesport.

Now referring back to Fig. 2, if, when the downward movement of the curve had been checked and started upward, point (d), the operator had begun to close off his over-supply by moving the valve to some intermediate position such as N'', somewhat more open than the previous normal, the line, instead of moving the point (e) could be made to return to the holding point at (f) and remain there as long as the new demand persists. The typical temperature line would then appear as shown at Y.

Automatic Operation—Two-Position Control

Now we substitute for our operator an automatic motor-driven mechanism. We will first consider a pyrometer having only 2 contacts, one "high" and one "low," and a valve-operating mechanism which can stop only at 2 positions, making these positions manually adjustable as to spread, so that they may be represented by S' and O', with more or less spread than that shown in the diagram. Obviously, the closer together they are, the better, provided always that the open position is large enough to supply the greatest demand which we are likely to have and that the closed position will be slightly less than the minimum demand. The pyrometer contacts will be set as close together as practicable, depending on the type of instrument in use.

This results in typical two-position control as described for manual operation. The inherently conflicting requirements are that better control will result when the 2 valve positions are as close together as practicable and that the closer they are together, the more restricted the system is in handling changes in demand. To minimize the overswing, we will try the effect of moving the pyrometer contacts closer together until the differential is nearly zero, and in all instances, this will improve the two-position control. We may even try to distort the temperature record so that it crosses the holding line ahead of the actual furnace temperature, thus anticipating the time of reaching the opposing corrective contact. Such expedients, whether they straighten out the temperature line or not, will increase the frequency of valve movements without reducing the extent of these movements, thereby introducing possibly undesirable reactions within the furnace which may overbalance any benefits derived from the straighter line. As a means of straightening the temperature line, this type of anticipation will give best results where the load is constant. Where load changes occur so that the time period which the valves rest on maximum and minimum is unbalanced, the result is likely to be a poorer temperature graph than would otherwise be obtained.

With the trend in furnace construction and operation calling for close control at a variety of loadings, some more flexible system of control is required, and it is necessary to design the mechanism so that it will be able to come to rest at one or more positions while the temperature is on the holding line. These positions, which we will call normals, will be in addition to the 2 extreme positions O′ and S′ to which we were limited in the two-position system. The more intermediate positions available, the greater chance that one of them will coincide with the demand of the moment, provided the opening assumed by the valve for a given temperature is greater on a falling than on a rising temperature. We can group the various systems about to be described under the

general heading below:

Multi-Position Control

Taking one step at a time in the direction of multi-position control, we next consider the *four-position system* which provides two normals in addition to the two extreme end positions. If we can provide a third circuit to the actuating motor mechanism which can be closed when the chart line is at or approaching the holding point and so arrange that the valve can be made to stop at some mid position as N'' when starting back from O' and at N' when returning from S', we shall have taken an important step in the direction of better control. The spread between N' and N'' will be made manually adjustable and if it should prove advisable in a given installation to make these two positions coincide, the result would be a *three-position system.*

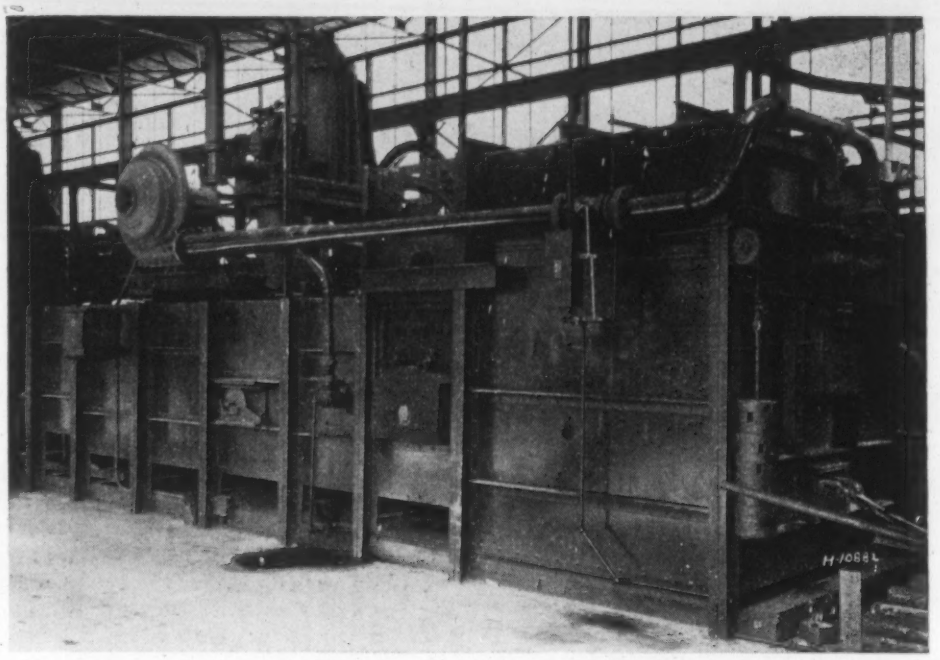
With this additional flexibility in fuel supply, we can spread the maximum and minimum valve positions and so widen the control range. How much this can be done with four positions depends on conditions. The spread between N' and N'', being manually adjustable, it can be made to cover the usual range of demand and if the latter should at times move outside this range into the zones $S'N'$ or $O'N''$, the mechanism will temporarily function as a two-position control within one or the other of these zones. We will expect to be at rest in the normal zone 25% or more of the time and can therefore have the end positions further apart. Under similar load conditions, we would expect to obtain regulation within approximately half the temperature swing possible with the two-position control or to hold the same temperature range with twice the demand range. Referring once more to Fig. 2, if we want the recorder to draw the curve cdf, instead of cde, it will be necessary to return the valve to some normal position before the line reaches point (f). We have shown this movement as taking place at (d) for it is at this point that the line starts to depart from a sine curve form. The relative time when this movement of return to a normal position is taken may seem of minor importance, but it may be the key to close control for a given job. For certain applications, point (d) may not be early enough to prevent an overswing and we must arrange to start the return to normal at the crest of the curve. This can be done by having recourse to special devices within the pyrometer which will "anticipate" the time of closing this normal circuit so that the valve will be made to return to its normal position when the temperature trend reverses at (c). This new system with two normals will not be ideal because it may well be that neither of our two fixed but manually adjustable normals, N' and N'', will exactly balance the changing demand which has caused the chart line to deviate. But certainly, one or the other must be much closer to the requirement than either O' or S'. And such deviations as may occur from this approximately correct normal will be less in extent and easier to correct. The chart line will now look something like Y and we will be able to hold this line with comparatively infrequent valve adjustments, which, in itself, is an important advantage.

Where departures from normal demand are of short duration and small in extent and where a moderate change in holding temperature during the time of any change in load is not objectionable, the use of a control system having an infinite number of valve positions on either side of one holding point will give practical results. This system provides that the controller moves its valves to a definite position for each value of the recorded temperature. The valves can be only at one position for each value of temperature recorded, which means that the temperature can only be at the desired holding point under one definite load condition, hence should an increase in loading occur requiring a more open valve position, it can only be obtained at the exepnse of a lower holding point. For general applicability, this system suffers from the fact that it cannot supply different rates of fuel flow while holding the same temperature.

A modification of the above system, which very much improves and broadens its scope so that it may be used under wider changes in fuel demand, consists of an arrangement whereby on a rising temperature each contact in the actuating instrument has a definite valve position supplying less fuel than supplied when the same contact is made on a dropping temperature.

Floating Normal

Suppose now that we are not satisfied with confinement to two or more fixed or semi-fixed normal or intermediate positions, but wish to go further and make sure that the normal position of the moment will always balance any change in demand within the range $O'S'$, Fig. 2. To accomplish this purpose, the normal will have to be capable of automatically shifting to any position required by the changing demand. It has already been shown that if we have for the moment a balanced condition in the furnace with the fuel supply just equaling the demand and a change in loading occurs which requires a more open valve position, we could not move the valve at once to that position even if we knew what it was and expect to regain promptly the desired temperature. The time lag makes it necessary to supply for a short interval an excess fuel flow over that required by the new loading. However, if we can return to the altered normal after the required interval, we will again have a balanced condition. Such a system may be called "floating normal."



Controllers on Holcroft Continuous Forging Furnace in Chevrolet Forge Shop

Balancing Control

In all temperature control problems, there are two different causes of temperature variation, one kind temporary and the other kind semi-permanent. In practice, they overlap but a careful study of conditions will usually enable classification under one or the other of these two headings. A few typical examples follow:

Causes for a temporary variation in temperature

1. Opening of the furnace door for a short period.
2. Clogging of burners by particles of dirt.
3. Sudden changes in wind velocity at top of stack.

Causes for a semi-permanent variation in temperature

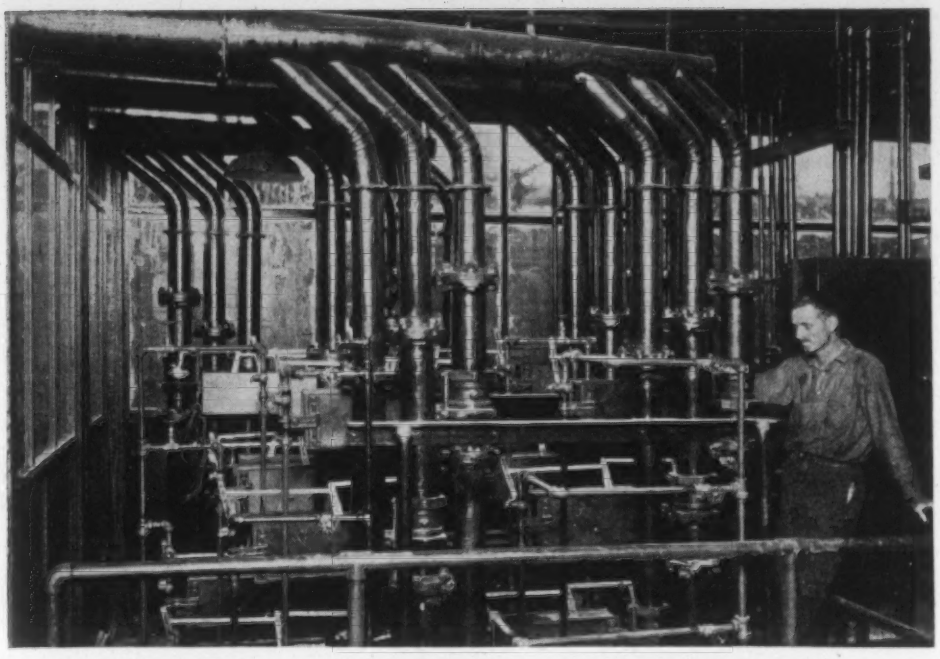
A. Increase in rate of furnace loading.

B. Increase or decrease of pressure in fuel line, due to adding to or withdrawing from service furnaces drawing fuel from the same source of supply.

C. Heating up of the furnace structure causing gradual decrease in the fuel demand for the same load conditions.

Temporary disturbances do not call for lasting changes in the normal fuel supply, but only for changes to prevent erratic drops in temperature. When the cause has ceased to exist, it is desirable to return the fuel valve to a position approximating the previous fuel supply. When more permanent variations take place a shift of the valve positions to a new fuel value is required. To meet both temporary and semi-permanent changes in fuel demand a system, which may be termed "balancing control," has several valve positions grouped around the normal setting, each having a definite fuel value when assumed on a rising temperature and a larger fuel value on a falling temperature. This group of valve positions, grouped closely about the average demand N of the moment as shown in Fig. 3, can be gradually or quickly shifted automatically so as to be disposed around the new demand point N', anywhere up or down the scale with reference to N.

There are applications where fuel demand varies over a wide range and may continue for some time at points which would be outside the range of O' to S', Fig. 2, yet very close control may be required at the demand point of the moment. An ex-



Pyrometer Room Showing Controllers for Three Hagan Heat Treating Furnaces in Chevrolet Forge Shop

ample, where balancing control will give results, is a continuous type furnace which may be called on suddenly to operate at partial load or where the loading may be stopped entirely for a period and yet it be required that practically no temperature change take place. Another example is that of Fig. 4 which shows results obtained with balancing control on a gas-fired forge furnace using inspirator type burners. As noted on the chart, the opening for inserting work was bricked up to conserve heat while the furnace was brought up to control temperature and during the course of the test, this opening was varied in size. The furnace brickwork gradually reached soaking temperature as the test progressed, thus causing a reduction in fuel demand without change in furnace load conditions. The air pressure in inches of water, marked alongside the temperature graph, is proportional to the amount of fuel used. It varied from 11″ to 2.2″ of water—equivalent to practically full opening to full closing of the valve, as full valve opening gave 12″ of water pressure while 1.5″ of water pressure was the minimum turn-down of the burners.

Other Systems

A system termed "floating control" which gives good results where lag is negligible (as in the control of pressure, flow or level) finds uses in certain temperature applications. For example, gas temperature regulation by the admixture of cold gas to produce constant temperature beyond the mixing point. In such a case, change in the rate of cold gas supply will produce change in mixture temperature with very little time delay. The control system would consist of a suitable valve in the cold gas line, operated by a "floating controller" designed to open or close the valve slowly in response to the making of high or low contacts at the point of measurement. With a fine-wire couple and no protecting tube, there will be practically no time lag and since the temperature of the mixture will respond rapidly to change in valve position, the motor can be allowed to run for the full period of the contact, stopping as the correct temperature is reached, the valve now being at the correct position to hold the desired mixture temperature, until another change takes place in the temperature of the primary gas. Should the motor travel be too rapid, an interrupter is placed in the motor circuit to slow it down the desired amount. Such a system, although ideal for a no-lag application, will not function with success under other conditions, because it does not provide quick over-travel to offset time lag.

Atmosphere Control

In certain applications, the maintenance of a correct and stable atmosphere is even more important than the maintenance of an exact temperature. To the question "Where does atmosphere come into the picture when discussing temperature regulation?" the answer is that changes in fuel supply may disturb atmosphere conditions. Whenever the control mechanism changes both the flow of air and of fuel, it should maintain a ratio between the two which will give the desired atmosphere in the combustion chamber. And even if this ratio be perfectly maintained, the mechanism must avoid, as far as possible, frequent and violent changes. In gas-fired furnaces, the use of inspirator burners relieves the control system of responsibility for proportioning the gas and air but still a sudden and considerable shutdown in the supply, with corresponding drop in pressure in the furnace, may change the atmosphere from reducing to oxidizing by reason of the stack effect which has been set up and which, until conditions equalize, will draw in excess air through burner ports, doors, peepholes and cracks. A control system which gives excellent results as to temperature may have a disastrous effect on atmosphere, due either to faulty valve design or to the method of control itself.

The designer of control equipment must here consider more than the valve-operating mechanism. The most important contribution which he can make is to design the two valves, in case two valves are used, so that the ratio of port areas, when once established manually, will not be altered during any movement which the mechanism will make or at any points where it may come to rest. When this condition has been fulfilled and when other means have been provided for maintaining constant the temperature and pressure of the air and gas as they reach the control valves (or, for an oil-fired furnace, the pressure and viscosity of the oil) then the volumetric ratio of the flow of the two mediums will not be altered. Too little attention has been paid to this important point by the designers of certain mechanisms who may furnish for the air and for the fuel, respectively, a butterfly type valve and a globe or needle type-valve which two cannot readily be made to work together to maintain constant "proportioning," since their characteristic flow curves are dissimilar.

Valve Flow Curves

Taking, as a basis of comparison, a constant pressure head through the valve, the flow curve of certain conventional designs of globe and plug valves will be approximately a straight line, as at *A*, Fig. 5, while that for a V-notch valve will be shaped like B, concave upwards. The curve for a butterfly valve is similar to *B* while for a needle valve, the curve is convex upwards, as at *C*. We may use two globe valves of different sizes, curves *A* and *A′*, Fig. 6, for the ratio of flow will be preserved throughout the range, provided the pressure and other characteristics of the medium remain unchanged. Likewise with the two V-notch valves, *B* and *B′*. But we cannot attain real proportioning with two valves whose flow curves differ in character. Yet this is commonly attempted. The further practice of allowing one valve to stop before the other does is equally destructive of true proportioning. Such combinations are usually found in two-position mechanisms, the evident idea being that, even with dissimilar flow curves such as *A* and *B*, Fig. 5, the two valves may possibly be adjusted to give the same ratio of flow at their two selected control points. While such an adjustment is theoretically possible, any manual widening or narrowing of the spread between the control points will impair the proportioning and, further, the proportioning will be destroyed during each movement of the valves. Since this movement may take place 20 times an hour and require 15 or 20 seconds to complete, the total time during which the furnace atmosphere is being altered from the desired normal is sufficient to require serious consideration.

In short the two valves must "team together," *i.e.*, must have similar flow curves and must be moved through similar increments of travel. The most suitable type of curve will depend on the conditions under which the system will be called upon to function. If the percentage change in flow from maximum to minimum setting is not very large and if the average demand point is in the upper third quarter of the range, as point *N*, Fig. 2, it makes little difference whether the curve be a straight line as *A*, Fig. 5, or a curve such as *B*. But for control in both the upper and lower portions of the valve range, as in the control of a furnace at full load and at no load, the *B* type of curve is to be preferred since close adjustment near the shut-off point, say below the quarter-open position, will be required and will be easier to make. For the average job where close control is required the conventional needle valve should be avoided, on account of the shape of its orifice and the resultant flow curve.

In discussing only the ratio of port openings we have assumed the constancy of pressure and temperature of the controlled mediums, without which flow would not vary directly as the area of the ports. This emphasizes the necessity of providing ample capacity in oil, gas and air mains up to the control

valves so that variations in demand at other locations in the plant may have negligible effects. Where oil fuel is used, it is customary to provide some pressure and temperature regulation near the pump station and if the latter has sufficient capacity and the mains are large enough, pressure variations at the point of use will be negligible. However, even though we should go further than this and install individual pressure regulators at each point of use, or seek to provide constant pressure to the burners by other means, we would still have to reckon with changes in viscosity which would alter fuel flow. In the matter of air supply, a blower of ample capacity with capacious air ducts will usually maintain nearly constant pressure at the point of use even though the requirements of other furnaces on the line may be varying. But if the air temperature changes, as it readily may during the day, we may expect to find noticeable and perhaps serious disturbance of furnace atmosphere. Various means for automatically compensating for these exterior variations are or will soon be available.

Where the furnace vents into a stack or where the design of the furnace itself involves stack effect, it often is necessary to provide draft regulation to equalize the pressure in the furnace and prevent a minus pressure which would induce air leakage. This draft regulation may often be mechanically or electrically interlocked with the main controller.

There are, of course, other elements in the control problem which have to be considered in selecting the most suitable type of valve, such as the pressure of the medium under control, whether the valve must be tight-closing, the relative ease of adjustment, etc.

Valve Sizes

A fault common to many installations is indiscriminate specification of the valve sizes. The choice of an over-sized valve, apt to defeat close control, often results from the prospective user's desire that the valve have a minimum pressure drop. The ideal condition is that of an oversize pipe ahead of the control valve, a valve with the smallest maximum opening that will pass the required maximum flow and then an oversize pipe leading to the burner. In order to put the control valve in actual control of the flow, it must be "the neck of the bottle." At its open position, the port area should be slightly larger than the combined areas of the restricting orifices in the burners which are fed through the valve. If the burner ports are "the neck of the bottle" it may be necessary to close down the oversize valve very considerably before any check in fuel occurs. Proper control requires that any movement of the valve will cause a corresponding change in fuel flow.

Fuel Economy

We come now to a consideration of the third furnace characteristic affected by the type of control. In a heat transfer device such as an industrial furnace or the furnace of a steam generating boiler, heat losses are lower when the heat supply at all times equals the demand than when the supply varies at a different rate from the demand. In the case of the steam boiler furnace, even though the steam demand may be constant, it is frequently found that through improper adjustment and control, the stoker, and more especially, the forced draft fan are running irregularly; first too fast, liberating too much heat, accompanied by excess air and generating too much steam with an accompanying rise in pressure, and then swinging to the opposite extreme with a slowing down of the fuel feed and draft accompanied by deficient air, unburned hydrocarbons and carbon monoxide. This alternate over- and under-firing contributes to inefficient boiler operation and the analogy holds true for an industrial furnace.

In the usual case under automatic control, a certain degree of over- and under-firing will have to be resorted to for control purposes but the less the number of changes in fuel rate per hour, the smaller these changes in amount and the longer the intervals during which the correct rate is being supplied, the lower the fuel consumption. It is evident now why the system of temperature control used will have an inevitable effect on economy and if we turn back to the comparison which has been given of two- and four-position control, it will appear that the former must necessarily be at a disadvantage in this respect, for it inherently involves more frequent changes in fuel rate and, usually, changes of greater magnitude. Generally speaking, the straighter the temperature line, the less the fuel consumption.

To bring out a comparison of results obtained with four- as against two-position control under similar conditions of furnace load, three charts are shown, Figs. 7, 8 and 9, all obtained from a gas-fired test furnace under identical furnace load conditions. The contact-making pyrometer, in addition to recording the temperature, was equipped with two additional mechanically operated pens, the left one recording changing load conditions, and the right one recording movement of the control valve in the gas supply line in response to temperature changes. The temperature changes occurred due to opening and closing the furnace door on a prearranged time cycle, using a cam driven by a synchronous motor. The time interval between horizontal lines on the chart is 20 minutes.

Chart Fig. 7 shows a variation from 778° to 820° or a total of 42° F. with the control valve in a half open position throughout the load cycle.

Chart Fig. 8 was made with the fuel valve connected to a two-position controller and the temperature was maintained within $\pm 5°$ of the control setting throughout the load cycle. Note that when the furnace load was heavy, the fuel valve remained longer in its maximum open position than in its minimum position and that this condition was reversed when the load was light.

A uniform high and low swing in the temperature graph of a furnace regulated with a two-position controller is shown at V, Fig. 2, and indicates that the controller caused the temperature fluctuations and not changes in the furnace load. Under such conditions, automatic control is a needless expense as a better temperature graph would be obtained by manually setting the fuel valves and leaving them half way between the minimum and maximum setting used for control. W, Fig. 2, is a record of two-position control where changes in fuel, draft or load conditions were counteracted by the controller.

Chart Fig. 9 was made with the fuel valve connected to a four-position controller but with the minimum and maximum valve settings the same as for chart Fig. 8. Note that more fuel is supplied when the valve is moved to normal from maximum setting, than when it is moved to normal from minimum setting, and that the temperature is held closer to the control setting a greater percentage of the time. Note also that the fuel valve has been at its maximum open position but a small percentage of the two-hour record so that the average fuel consumption has been less than for two-position control under similar conditions as shown in Fig. 8. Comparing the two temperature graphs, the plus and minus variations are the same in extent, hence it is reasonable to expect that the temperature variation of the work was comparable. Since the temperature changed more frequently with two-position than with four-position control, however, the furnace atmosphere condition will be less stable, although properly designed fuel valves interlocked with damper regulation would tend to overcome this fault. Depending upon the furnace design and its characteristics, fuel consumption will be less by some percentage with four-position as compared with two-position control.

Conclusion

Control equipment has been developed from the two-position to more elaborate mechanisms which have, for their justification, greater adaptability to the increasing demands of industry. These improved control systems have made it possible to increase the working range of the furnace, improve the furnace atmosphere conditions, improve the fuel economy and also to provide closer temperature regulation. The intending purchaser frequently asks how closely a certain type of control equipment will hold the temperature of his furnace. The question indicates an incorrect approach to the subject, since, as we have tried to show, the extent of temperature swing is not the summation of control and therefore the relative value of one system over another should not be judged by this criterion alone. Obviously, no honest answer can be given to the above question, as it involves characteristics of the furnace and accessories which are usually unknown to both seller and buyer and which can only be determined by experiment.

Finally, price is an untrustworthy guide to selection of control equipment, since the difference in cost of the "best one for the job" over the cheapest is not great and the better mechanism may save this difference within a short period of operation.

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The organization of the Vascoloy-Ramet Corporation was announced September 1, 1933. This company is a consolidation of the tantalum carbide manufacturing divisions of Vanadium-Alloys Steel Company, Fansteel Products Company, Inc., and Ramet Corporation of America.

Effective September 1, 1933, the products of the Vascoloy-Ramet Corporation will be offered under the trade name of "Vascoloy-Ramet" only through the Vanadium-Alloys Steel Company's sales department and its duly appointed sales agencies, including the heretofore sales agencies of the Ramet Corporation of America.

HEAT-RESISTING CR-NI-FE ALLOYS FOR FURNACE CONSTRUCTION

By L. J. Stanbery*

Part II. Selection of Alloys for Specific Conditions of Use

The available information on load-carrying ability of the Cr-Ni-Fe alloys for high temperature service was collected in Part I. Were that the only important factor, one would need merely to balance the strength (assuming that it were really known) against the cost, when the choice, for any given temperature range of service for a desired length of useful life would be merely a matter of a little arithmetic.

The task is, however, much more complex and difficult. The alloys are not equally suitable for different conditions of use, they are not equally easy to produce sound and free from internal defects nor are they equally stable in properties under high temperatures.

An important factor in the serviceability of an alloy is the nature of the atmosphere in contact with it. In oxidizing atmospheres that are free from sulphur gases the presence of 15 to 25% Cr, according to the temperature, is sufficient to give good protection against scaling. At temperatures around 2000°F., the higher Cr content is called for. Moderate amounts of Ni, say up to an amount equal to the Cr content do not materially alter the resistance to oxidizing conditions. When the Ni far overbalances the Cr and the alloy is subjected to frequent and drastic changes in temperature there may be some tendency toward flaking of the protective oxide coating, more marked in wrought than cast alloys.

A "neutral" condition from the combustion point of view in fuel-fired equipment may be slightly reducing from the point of view of the metal surface. In the absence of sulphur gases this is not especially harmful. Highly reducing atmospheres are, however, harmful. Such atmospheres may contain CO, CO_2, hydrocarbons, hydrogen and water vapor. While they will scarcely reduce the oxide coating and give a bare metallic surface there is probably enough of this tendency to make the coating somewhat permeable, and hydrogen or perhaps CO_2 may penetrate and remove carbon from the carbides in the grain boundaries near the surface. Fissuring of the boundaries follows and embrittlement and intergranular attack ensues.

When the atmosphere contains sulphur gases, it is much more dangerous to the alloys containing Ni. The Ni-free or the low-Ni alloys of Cr and iron are therefore indicated when high-sulphur atmospheres are present. The necessity of meeting such conditions is the chief reason for using the plain Cr alloys, but their usefulness is limited by their tendency toward large grain size and resultant room-temperature brittleness. This tendency is combated by the presence of Ni and the creep strength is raised, so the use of Ni is advisable, perhaps up to the limit that the atmosphere will allow. The sensitivity of the Ni-containing alloys, while real, is often overestimated and in combination with sufficient amounts of Cr, say at least equal to the Ni, considerable amounts of Ni can be tolerated even in the presence of fairly high sulphur content in the gases.

The sulphur gases are less harmful under oxidizing conditions, when they are present chiefly as SO_2 (perhaps SO_3, though less frequently) but even under oxidizing conditions, fuels with over 0.50% S, in oil, or 100 grains per 100 ft.^{3}, of gas tend to have a bad effect, chiefly that of general corrosion.

Under reducing conditions, with the S present as H_2S or organic S compounds the attack is much worse. Ni and iron, especially, are very readily attacked. The addition of Al is claimed to combat this attack to some degree and to allow the use of a relatively high ratio of Ni to Cr. H_2S will greatly accentuate the intergranular attack in reducing atmospheres. For this reason, one has a much wider choice of alloys for service in electric furnaces with oxidizing, S-free atmospheres than in fuel-fired furnaces that may operate with reducing and high S atmospheres.

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Beside the composition of the atmosphere, the nature of the alloy comes into play also. Some of the alloys are metastable and may deposit Cr carbides in the grain boundaries after long exposure at certain high temperature ranges. When this occurs, the boundaries are particularly sensitive to decarburization and to H_2S attack. Below the critical temperature range of deposition of carbides they are less sensitive. At still higher temperatures the carbides may go back into solution and the sensitivity again be lost. The critical carbide range will vary with the composition and previous treatment of the alloy. Hence we must know not only the nature of the atmosphere but also the range of temperature at which the alloy is to be exposed to that atmosphere.

From this point of view, the lower the C content the better, in opposition to the requirement for maximum creep strength, which rises with C content in most commercial alloys.

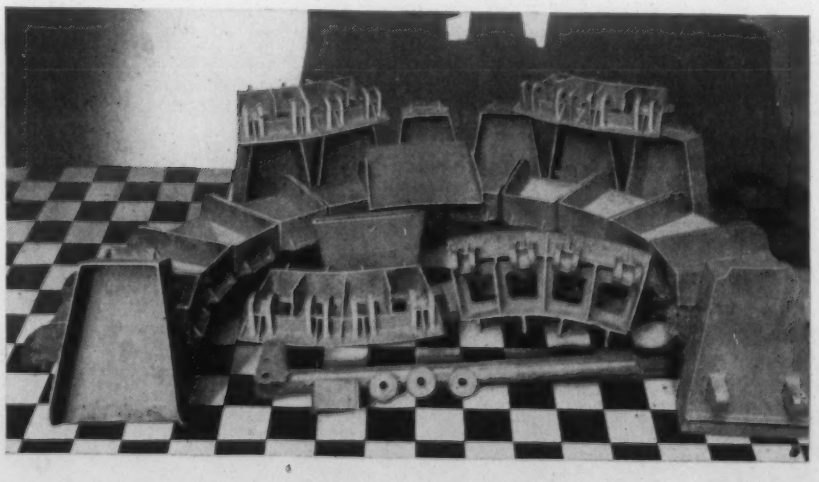
While it is not accepted by all, some authorities advocate a Cr content of 15 to 25 times the C content plus 12%, and for severe S conditions, a Ni content of not over half the Cr. As a definite amount of Ni is required for complete austenization and hence for creep strength, the C and the atmospheric requirements often build the Cr up, for reducing S atmospheres, far above the minimum needed for protection against oxidizing conditions.

General attack by S, as contrasted with intergranular attack increases with temperature and is very serious over 2000°F. It may be necessary to reduce the Ni down to the point where the alloys are ferritic, or even to use Ni-free alloys, with consequent loss in load-carrying ability.

Any serious condition involving abrasion, so that the protective film is continually removed, of course materially shortens the life in any atmosphere.

Having eliminated the compositions not suitable for the atmospheres in question, the question of the stability of the remaining alloys must be considered in any application. This will be briefly dealt with in the discussion of the different groups of alloys. For conciseness of discussion it is necessary to set up classifications or groupings. No two experts will agree on the exact limits of composition for the different groups and many would subdivide the alloys into a large number of groups. Those given below are arbitrarily chosen, but will serve as a basis for discussion.

There are many commercial analyses available in wrought and cast form under various trade names. Many of them are substantially duplicates of each other as to typical analysis.



Nichrome Furnace Castings
(Courtesy Driver-Harris Company)

The ternary diagram, Fig. 1, indicates the possible combinations from the mixture standpoint. Not all of these are commercially practicable, either because of extreme brittleness, inability to cast successfully, or inability to roll into shapes. The shaded areas indicate the approximate limits of the alloys which have proven commercially important as structural metals at high temperatures.

In general, the most useful alloys may be divided into 5 classes:

1. Austenitic High Nickel-Chromium
   (Nickel 50.0 – 80.0%)
   (Chromium 15.0 – 20.0%)
2. Austenitic Medium Nickel-Chromium
   (Nickel 25.0 – 50.0%)
   (Chromium 15.0 – 20.0%)
3. Austenitic Chromium-Nickel (High Nickel)
   (Chromium 20.0 – 30.0%)
   (Nickel 18.0 – 25.0%)
   (Slightly metastable below 1500°F.)
4. Austenitic Chromium-Nickel (Low Nickel)
   (Chromium 20.0 – 30.0%)
   (Nickel 8.0 – 15.0%)
   (Strongly metastable below 1500°F.)
5. Ferritic Chromium-Iron
   (Chromium 15.0 – 30.0%)
   (Nickel 0.50 – 6.0%)

These basic analyses are produced with varying amounts of C, Si and Mn to suit requirements and are occasionally modified by small additions of secondary alloying elements such as Mo, W or Al to fit special cases. The limits as listed above are for classification purposes only, the actual commercial specifications being confined to a smaller range as allowances above and below the desired quantities.

Alloys of above 30% Cr and with approximately equal Ni and Fe content, shown by Tucker and Sinclair[1] to have the best creep resistance at 1600°F., are not commercially used because their inherent brittleness has not yet been overcome.

The high Ni-Cr alloy No. 1, is no longer used as a structural alloy except in special cases, as its load-carrying ability is not appreciably greater than the other austenitic alloys and, when the Ni content is in the upper ranges (65 – 80%), may be considerably less. Its cost is high due to the high Ni content and as a consequence it is rarely used except for special purposes such as carburizing boxes, resistance elements for electric heating, etc.

The medium Ni Ni-Cr alloy No. 2, has had a wide popularity because of its medium cost, malleability, stability of phase, ease of casting and high strength. It is an excellent combination for general use when the high temperature atmospheres are free from S, such as those from the combustion of natural gas and the average city gas. Appreciable amounts of S in the fuel will, however, result in a decided attack. For operations in clean gases and under a continuous and steady temperature so that flaking of the protective coating due to the temperature changes are avoided, this alloy has a well deserved and widespread use. It has the advantage of being tough and ductile under all conditions of service. It will be noted in the ternary diagram, Fig. 1, that it is truly stable as to austenitic phase within the range of useful temperatures, and as such, practically insensitive to critical temperature ranges.

Alloy No. 3, the Cr-Ni combination with the Cr equal to or in excess of the Ni content, is perhaps, the most useful of the five listed. It is practically immune to S attack when the S is less than 1.0% or 250 grains per hundred cubic feet in the fuel, and the conditions of service such that the metal is not continuously exposed to strongly reducing atmospheres in the temperature range 1200°-1350°F. Its strength is slightly greater than No. 2 for temperatures up to 2100°F., and quite considerably greater than No. 1, up to 1950°F. While it is not truly austenitic at all temperatures, being slightly metastable below 1500°F., the tendency to revert to the ferritic phase is small.

A strong advantage of this alloy is the tendency of the Cr-rich protective scale to remain intact over a wide range of temperature variations. It is somewhat less malleable and ductile than alloys No. 1 and 2, and in the cold state is harder due to the high Cr content. It is also somewhat more difficult to cast than the other two. Because of the advantages just mentioned, this alloy has had an extensive application to steel mill equipment where quite appreciable amounts of S are often present in the available fuels. Its cost runs a little less than No. 2, and considerably less than No. 1, because of the lower Ni content.

The Cr-Ni combination with low Ni content, No. 4, finds an extensive application where strength is required coupled with resistance to highly sulphurous atmospheres, that is, up to 3.0% or 500 grains per hundred cubic feet in the fuel. This combination is rather dangerous to use at medium temperatures ranging from 1100°-1450°F., as it is strongly metastable

[1]W. A. Tucker & S. G. Sinclair, Creep and Structural Stability of Ni-Cr-Fe Alloys at 1600°F. *Bureau of Standards Journal of Research*, June 1933, pages 851-862.

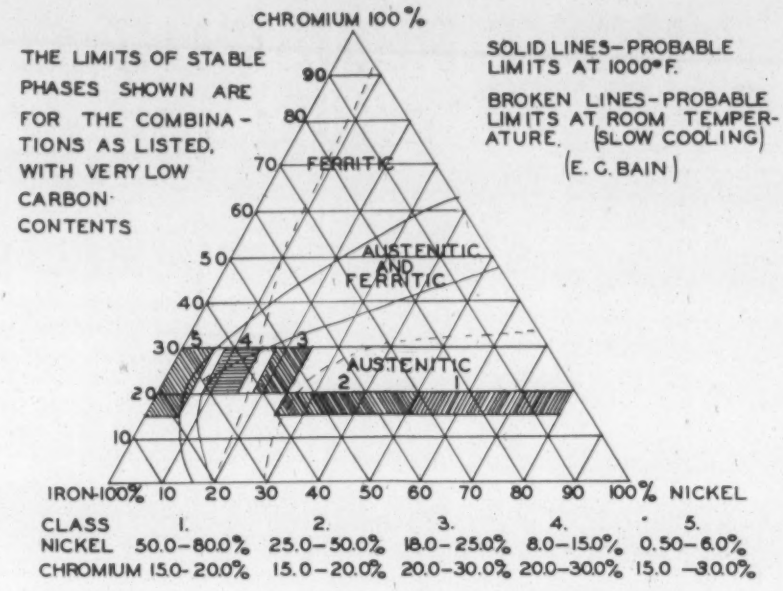

CHROMIUM 100%
THE LIMITS OF STABLE PHASES SHOWN ARE FOR THE COMBINATIONS AS LISTED, WITH VERY LOW CARBON CONTENTS
SOLID LINES – PROBABLE LIMITS AT 1000°F.
BROKEN LINES – PROBABLE LIMITS AT ROOM TEMPERATURE. (SLOW COOLING)
(E. G. BAIN)
FERRITIC
AUSTENITIC AND FERRITIC
AUSTENITIC
IRON 100%
NICKEL
CLASS 1. 2. 3. 4. 5.
NICKEL 50.0–80.0% 25.0–50.0% 18.0–25.0% 8.0–15.0% 0.50–6.0%
CHROMIUM 15.0–20.0% 15.0–20.0% 20.0–30.0% 20.0–30.0% 15.0 –30.0%

Fig 1. Location in Ternary Diagram Chromium-Nickel-Iron Alloys

in this range. If exposed for appreciable periods in the critical temperature range, it may partially revert to the ferritic phase and may also become extremely brittle and sensitive to the effect of a reducing and sulphurous atmosphere. Because of this characteristic, this alloy often is not as resistant to the attack of S in the medium temperature range as the higher Ni and more stable alloy No. 3. Above the critical range, however, this alloy has a high resistance to S attack and a strength but little less than the other three listed.

When the use of this alloy is necessary, the Ni and C contents should be carefully controlled, the Ni being as high as S conditions will allow, and the C as low as possible so that carbide formation and intergranular corrosion is retarded. Casting problems, while slightly greater than in the alloys previously discussed, are amenable to good foundry practice. The cost is about equal to that of alloy No. 3, as the advantage of the lower Ni content is offset by the higher cost of the low-C ferro-Cr necessary in the melting charge for low C specifications. It is possible that future investigation of the effect of certain secondary additions will permit the suppression of the changes at the critical temperatures with attendant increase in the usefulness of this alloy. The majority of the commercial rolled heat-resisting alloys lie within this group, although there are a few which belong to Nos. 2 and 3.

The ferritic alloys of class No. 5, are usually applied when S conditions are extreme or when the structure needs only to resist oxidation with no particular demand for strength. These alloys are much lower in creep strength than the austenitic series. While some of the Cr-Fe alloys become austenitic at high temperatures, they quickly revert to the ferritic phase at lower temperatures and to be safe in application they are treated as wholly ferritic over the useful range. A serious drawback to the more extended use of the ferritic alloys is the tendency toward room temperature brittleness as the result of continuous exposure to the temperature range 750°-1100°F. The alloys are not brittle at these temperatures but are very much so after long exposure to them. This embrittlement is removed by reheating to 1300°F., but as in the case of the metastable austenites, the expedient does not remove the underlying cause and the condition may be expected to re-occur when the critical range is again encountered. These alloys when in the wrought condition are also susceptible to a considerable grain growth when exposed to temperatures above 1900°F.

Except in the range 750°-1100°F., these alloys are almost immune to the effects of ordinary high-S atmospheres and are strongly resistant to oxidation. Because of their lower strength and tendency toward embrittlement, however, they have not had as extended use as the austenitic type. Moreover, their strength over that of ordinary steels as compared to their increased cost does not give the return in serviceability that is attained by the austenitic type.

Ni is often added in small quantities to the ferritic alloys in order to restrain grain growth and to increase the toughness. When added in quantities approaching those in class No. 4, however, the alloys should be considered as austenitic above 1500°F. When the special characteristics are carefully weighed, excellent use can often be made of the ferritic alloys at low cost as compared to the austenites.

All five classes are available as castings and, if required, as wrought products. As a rule, however, only class Nos. 3, 4 and 5 are widely available as commercial sheets, plates and bars.

Q-Alloy CNl retort used for pigment treating in a controlled atmosphere, temperature 2000°-2100° F., by one of the large color and chemical manufacturers. Length 23 ft., wall thickness ½". Composed of six sections welded together, supported on rollers to allow for expansion. Equipped with 125 ft. of specially designed chain and conveyor pans, of special analysis. (Courtesy General Alloys Co.)

In class Nos. 3 and 4, the Cr and Ni contents are about the same in cast and rolled products. The C content in castings, however, is usually higher than in rolled products, as C is required to impart fluidity in pouring castings which are relatively intricate as compared to the simple ingot pouring problems of rolled products. In addition, the higher C content of the casting obtains a higher creep strength at the expense of ease of manipulation which is necessary for the commercial forming of wrought products.

In castings from alloys No. 1, 2 and 3, the C content usually runs from 0.30% to 0.60% or sometimes higher. A specification will usually allow a 10 point range. In cast alloys Nos. 4 and 5, the C is generally as low as can be successfully cast (0.15-0.25%), except that in certain cases where great hardness is desired at medium temperatures the ferritic alloy No. 5 may contain as high as 1.50% C.

In rolled products such as sheets for normal forming operations and the average corrosion conditions, the C is usually held at 0.20% maximum. Certain exceptionally severe corrosion problems may demand a maximum C content of 0.07% which requires somewhat special charging material and melting methods with consequent increased cost over the 0.20% maximum C material of the same classification.

It should be noted that commercially attainable low C contents do not necessarily inhibit the changes in the metastable austenites such as Nos. 3 and 4, at critical temperatures, but by the reduction of the amount of carbides formed by precipitation, the embrittlement and sensitivity to corrosion are minimized.

We may consider the alloys not only from the point of view of composition but also from that of suitability for fabrication and for casting. Let us first take up the wrought alloys. Some of the salient characteristics of the most generally used rolled Cr-Fe and Cr-Ni-Fe alloys are summarized below:

1. Chromium-iron-carbon — Chromium 18.0-28.0%
   - (a) Highly resistant to oxidation
   - (b) Highly resistant to corrosion (S)
   - (c) Lower cost than the chromium-nickel alloys
   - (d) Easily fabricated when in the proper condition
   - (e) Susceptible to grain growth at high temperatures
   - (f) Brittle at room temperature after long exposure to a critical temperature
   - (g) Brittle in area adjacent to weld due to grain growth
   - (h) Low creep strength above 1000°F. compared to the austenitic type

2. Chromium-nickel-iron-carbon — Chromium 18.0-30.0%, Nickel 8.0-25.0%
   - (a) Highly resistant to oxidation
   - (b) Resistance to sulphur corrosion depends on carbon and nickel contents, treatment, grain size and exposure to critical temperatures and atmospheres
   - (c) Higher cost than chromium-iron-alloys
   - (d) Easily fabricated when in the proper condition
   - (e) Substantially free from grain growth at high temperature within the range of useful temperatures
   - (f) Brittleness resulting from critical temperatures will depend on carbon, nickel, treatment and grain size
   - (g) Brittleness in area adjacent to weld depends on carbon and nickel content and subsequent treatment
   - (h) High creep strength as compared with ordinary steels and chromium-iron alloys

Comparing the two types of alloys under the best set of conditions for each we may say:

(a) Equal
(b) Equal
(c) Chromium-iron has advantage
(d) Equal
(e) Chromium-nickel has advantage
(f) Depends on temperature of service but equal outside of respective critical ranges
(g) Chromium-nickel has advantage
(h) Chromium-nickel has advantage

The only real advantage possessed by the chromium-ferritic type is cost. On the other hand, the serious difficulties incident to a deficiency in the values of (e), (g) and (h) outweigh the apparent advantage of cost.

Many sources of unsoundness prevalent in castings are eliminated from rolled products by properly cropping the ingot and chipping the billets.

Rolled heat-resisting alloys are peculiarly susceptible to their mill history. Occurrences in the steps of reduction from the ingot to the finished products may affect the performance of the alloys in the hands of the user. Between certain of these steps the metal cools below the proper working temperatures and reheating is necessary to restore the plasticity before further reduction is to be attempted.

Mention has been made of the tendency of the metastable alloys to revert from the unstable phase to that normal for the temperature under consideration. Also, due to the tendency of the grains to grow in size at very high temperatures, mechanical manipulation must be completed at temperatures below the recrystallization point if a fine-grained structure is required.

Newell[2] and others have found that a fine-grained structure suffers from the ill effects of heating at critical temperatures to a lesser degree than a coarse-grained structure. As the grain-boundary area is greater in the fine-grained structure than in the coarse-grained one, there is less possibility for the formation of networks of carbide for a given amount of precipitation. In other words the carbides in fine-grained structures will be isolated from each other, and the effect of disintegration due to carbide decomposition and intergranular corrosion will be less than that caused by the decomposition of networks completely around the grain.

For the same reason, fine-grained material will show less embrittlement on exposure to critical temperatures, as the lack of continuity of the brittle carbide network will allow the high-temperature plasticity of the grain-boundary to persist to a greater degree.

It is obvious then, that the temperatures of rolling, reheating and annealing will, to a large extent, govern the condition, structure and final performance of the rolled alloy. A metastable alloy if worked in the critical or precipitation range has a double tendency toward phase change and carbide formation due to the mechanical working and temperature influence. As a consequence, reheating operations on alloys should be carried out at temperatures sufficiently high to allow substantial re-solution of the C but not so high as to allow excessive recrystallization and grain-growth. Finishing temperatures must be carefully controlled to produce the desired grain size.

The final operation to put the product in the form in which it is most resistant to oxidation and corrosion and which will allow ease of fabrication is to soften or anneal the metal.

Ordinary C and low alloy steels are annealed by heating to above the critical ranges and cooling slowly. This also applies to the high-Cr ferritic alloys with the reservation of a necessity of rapid cooling in the range 1100°-750°F. to prevent embrittlement. However, the undesirable hardness in the austenites is eliminated by heating to a point where the C is in solution and the structure wholly austenitic, and cooling rapidly by quenching, either in air as for thin sections or in oil or water for the heavy sections. Rapid cooling is necessary, as slow cooling would allow a partial reversion to the ferritic phase by the more unstable alloys at critical points of the temperature gradient. (See Fig. 1.)

Caution should be exercised in the case of the highly metastable alloys as a too drastic quench such as water may set up strains by contraction stresses, and may even produce a certain amount of martensitic structure. The rate of cooling is critical and should be the result of careful experiment. The use of mixtures of soluble oil and water, or even commercial quenching oil will usually produce satisfactory results for heavy sections such as bars and plates and heavy sheets. Sheets $\frac{1}{16}$" or under in thickness, rarely require any other quenching than exposure to the air.

[2]H. D. Newell. Influence of Grain-size on the Properties and Corrosion Resistance of the 18-8 Iron-Chromium-Nickel Alloy for Elevated Temperature Service. *Transactions American Society for Steel Treating*, Vol. 19, 1931-1932, pages 673-732. Alloy Steel Tubes for Refinery Service. *Refiner and Natural Gasoline Manufacturer*, Vol. 12, April 1933, pages 122-131.

The proper annealing of the austenitic alloys offers a problem in that a temperature sufficiently high to allow complete re-solution of the C and establishment of the austenitic phase may also be within the range of re-crystallization and grain-growth, thus wiping out the fine grain size attained by finishing at the proper rolling temperature.

The user may control to a certain extent, the condition of the metal he purchases, by specifying a maximum annealing temperature to control grain-size, and a hardness limit to insure proper forming characteristics. For alloys Nos. 3 and 4, the limit of hardness for sheets should be Rockwell B-75 maximum and for plates and bars B-80 maximum. For the high Cr alloy No. 5, B-75 maximum for both sheets and heavier stock will be allowable. For alloys rolled from alloy No. 2, such as the 25% Ni 18% Cr type, the maximum for sheets can be B-70 and for plates and bars, B-80. It is probable that after thoroughly analyzing the individual fabricating problems of a user, a more searching test such as the Erichsen, or a bend test, will allow a simpler means of checking the condition of purchased material.

A little-understood but occasional source of trouble which has its origin in the mill history, is the condition similar to the phenomenon known as "season-cracking" encountered in certain non-ferrous alloys. When sheets are formed or welded in the fabrication shop, occasionally cracks appear in the metal at some distance from the point of operation, which apparently have no relation to the severity of the operation. These cracks may appear immediately during the working of the metal, or they may show up later while the structure is in service.

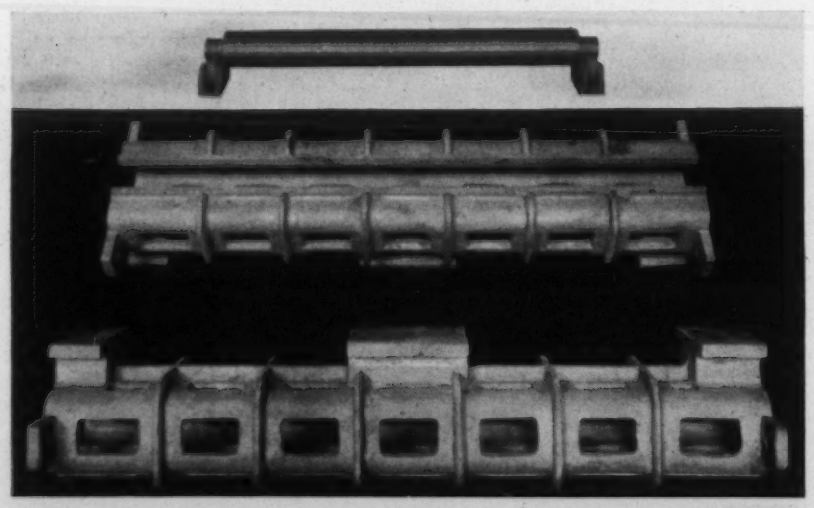
The causes are, too drastic reduction during working or rolling because of a low rolling temperature, insufficient heating between rolling operations, or the presence of slag inclusions which break up the continuity of the metal. The cracks are incipient and invisible on visual examination of the sheet, even after strong pickling. A careful etching of affected areas plus low-powered micro-examination will reveal cracks in the grain-boundaries. They are similar to the cracks characteristic of material overstressed at high temperatures.

Under the stresses set up by forming operations or those induced by different rates of expansion in hot and cool areas of parts undergoing welding operations, the intergranular cracks open up and extend until they assume large proportions and penetrate within the grain.

The condition frequently appears in material which has been over-stressed during rolling and then set aside for some time before reheating or annealing. Metal under suspicion of this condition should be reheated within 30 minutes after working, to relieve the strains set up by working. Once the cracks are in the sheet they are in there to stay and can be eliminated only by remelting. Cracks of this nature in clean alloys are attributed to too drastic reduction from the sheet-bar. When induced by slag inclusions, the cause goes back to the nature of the charging scrap, melting practice, ingot cropping practice and the amount of care exercised to eliminate surface defects in the bloom and billet.

The serious aspect of this condition is that it usually appears in the fabrication shop of the user who naturally feels justified in scrapping the whole heat. Because of its nature, no routine mill inspection is available to detect material in this condition short of destructive forming or 100% etching and microscopic examination.

Q-Alloy hollow cast and precision ground power driven conveyor roll, with section of continuous roller bearing unit. (Courtesy General Alloys Co.)



Combination supporting guide and inverted roller rail for special continuous hardening furnace. Made in Q-Alloy. Total of 24 used in furnace. Conveyor chain supported by rollers traveling in rails shown in photo—special carriers are carried by chain, automatically detached from chain at discharge and quenched with work. (Courtesy General Alloys Co.)

Embrittlement incident to exposure to critical temperatures may be removed after a fashion by periodic reheating to temperatures above 1750°F., but when the metal is essentially metastable, this expedient only postpones the effect and does not eliminate the cause.

Phase changes similar in principle to those induced by critical temperatures may be induced by cold working the metastable alloys but are not usually as serious. The C precipitated as the result of such changes usually forms submicroscopic carbides along crystallographic planes within the grains. While the sensitivity to corrosion is not greatly increased by the precipitation incident to cold-working because of the carbides being confined within the grains, the combined effect of cold-working plus exposure to critical temperatures may result in extra sensitivity in the areas affected by the forming. The remedy for the ill effects of cold-working, such as hardness and increased sensitivity, is to restore the austenitic phase by raising to the proper temperature and quenching. This temperature should be about 1900°F., for quickest and best results, as a higher temperature may induce grain-growth, and a lower temperature require too long a time for complete solution of the C.

When intergranular corrosion due to exposure to corrosive gases while in a sensitive condition has progressed to an appreciable amount, the metal can not be restored short of remelting. Failures due to intergranular corrosion are generally characterized by distinct disintegration and a loss of the normal ringing sound when the metal is struck or dropped on a hard surface. Most failures, however, are caused by a combination of intergranular corrosion causing "rotten" metal plus an embrittled condition from carbide formation, both being due to exposure to critical temperatures.

When the metal is in this condition, sudden mechanical and thermal shocks produce cracks in the affected areas and failure results. Failures of this character are common in sheet structures and generally occur, not in the hottest parts of the structure, but in the sections where critical temperatures occur in the metal.

Turning now to cast alloys, the composition within a given class naturally varies somewhat from that most suitable for wrought alloys, since castability, not workability, is sought.

It is necessary to pour heat-resisting alloys at as low a temperature as is consistent with good fluidity. The metal by its very nature solidifies rapidly and when the castings have sections of varying thicknesses, the thick sections will cool somewhat more slowly than the thin ones. The forces of contraction set up by the rapidly cooling thin sections exert large stresses on the hotter and more plastic heavy sections and since by reason of higher temperature the heavy ones have a lower strength, there is a tendency to draw and produce unsound areas.

Si acts as a strong deoxidizing agent in melting, imparts fluidity when pouring thin and intricate castings, and assists in maintaining a tenuous, tough coating as a protection against oxidation and general corrosive attack. Some producers claim that in wrought alloys it contributes to ease of rolling, which would indicate that at very high temperatures it might decrease rather than increase strength. There is a difference of opinion as to whether Si as an alloying addition to the Cr-Ni austenitic alloys actually increases the high temperature strength. It certainly contributes to the strength of castings by promoting soundness through increased fluidity at pouring temperatures and hence better ability to fill the mold at low pouring temperatures.

C assists in maintaining fluidity at low pouring temperatures but when decreased due to the demands of service, an appreciable Si content is usually necessary for soundness of section. C content for castings will vary with requirements but as a rule is much higher than in wrought alloys.

Mn is present in all of the alloys under discussion because of its use as a deoxidizer during melting and because of its ability to bind S as MnS. Some rollers believe that like Si, high Mn (1.0-1.5%) in wrought alloys, contributes to ease in rolling.

When present in quantities in excess of 2%, the effect of Mn is toward embrittlement and possibly toward lower creep strength.[3] This effect persists up to about 10%. Beyond this point the effect is toward establishing and stabilizing the austenitic phase, as Mn acts somewhat in the manner of C and Ni in lowering the transformation point at which austenite is formed. Castings of austenitic Cr-Mn have been reported to crack in the mold. Proper balancing of Cr, Ni and Mn content might avoid these difficulties while at the same time reducing the cost by requiring smaller amounts of the expensive Ni.

[3]C. L. Clark & A. E. White. Comparative Physical Properties of Cr-Ni, Cr-Mn and Mn Steels. *Transactions American Society of Mechanical Engineers,* No. 53, 1931, page 177-189.

Certain austenitic Cr-Mn-Ni-Fe alloys are now being investigated as substitutes for Cr-Ni alloys in severe S conditions but no definite conclusions as to their value and creep strength are available.

P and S are considered as harmful impurities and are kept at commercial minima in these alloys, either by using charging materials of low P and S content in the acid melting process or by substantial removal by the basic method. Most alloys of this class are produced by the acid process although there are a few producers who prefer the basic method. Either method is satisfactory when properly supervised.

Summarizing, the elements normally present in heat-resisting alloys other than the distinguishing Cr, Ni and Fe contents are generally specified as follows:

Element	Castings	Wrought Alloys
Carbon	0.20-0.50%	0.20% Maximum
Silicon	0.50-2.00%	0.25-2.50%
Manganese	0.50-1.50%	0.50-1.50%
Phosphorus	0.025% Maximum	0.025% Maximum
Sulphur	0.025% Maximum	0.025% Maximum

Other additions to the Cr-Ni-Fe alloys are secondary and have been studied more for their effect in combating corrosion and preventing carbide separation in welding, rather than for their effect in high temperature service. Of these, W, Mo, Cu, Co, Al and Ti have received the most attention and have been used singly and in combination. Their exact effects on the high temperature creep resistance have not been fully determined as yet, although there is plenty of evidence that W and Mo are decidedly beneficial. It is highly probable that as their effects are investigated more fully their addition in the proper amounts and combinations will greatly increase the usefulness of the present alloys.

However, the factors of increased strength and corrosion resistance must be accompanied by ease in production and soundness of section in order to be of real value, and the increase in cost must be accompanied by increase in good qualities in order to be of benefit. Whatever the composition chosen, the factor of soundness in castings may be of far more importance than considerable variations in analyses.

The modern alloy foundry resembles the average steel castings foundry as far as equipment is concerned, and to the casual observer, the methods of melters, molders and ladlemen are the same. Both dry and green sand molds are used, and coring practice is about the same in both types of foundry.

But certain special features of high grade practice, which are only used in the steel foundry in cases of difficult and very important castings, are of necessity the routine method in the alloy foundry. The very use for which the castings are intended implies that their metal will have at pouring temperatures, characteristics not possessed by simple and low alloy steel castings. The heat-resisting alloys quickly lose fluidity as the melt cools, and they solidify more rapidly than the ordinary steels. Due to the rapidity of solidification and the influence of unequal sections on the cooling rate, the occurrence of such defects as "shrinks," "cold-shuts," "laps," and variations in grain size in different sections due to the different cooling rates, etc., defects may appear which are highly important.

Many problems must be solved in the preparation of the pattern and mold before the metal is poured in order to avoid these defects. The severe service for which alloys of this class are intended is such that the best of castings are none too good. There is no chance to eliminate minor defects by ingot-cropping and billet chipping and turning as in the rolling mill. An unsound casting should be a scrapped casting. Inherent defects which in rolled products may be minimized by subsequent mechanical manipulation are in the casting to stay.

The designer can produce far more assurance of safe and economical service by adapting his structures as far as possible to good foundry practice, than the metallurgist, who at best can make only minor adjustments of analysis. The argument that mechanisms are designed for the sake of the production operation and not for the sake of the mechanism is quite right, but coöperation between the purchaser and producer will assure a maximum of operational continuity and a minimum of shut-down charges.

The foundryman should be made acquainted with the exact nature of the service which is to be rendered by the casting, and he can often suggest certain minor changes in design which will aid in producing a better casting without altering the general plan of the mechanism as a whole. If the specific requirement of design is such as to create unsound sections and due to certain limitations, the design can not be altered, the metal section must be increased by a safe margin in order to properly anticipate the condition.

The use of extremely thin sections is not advisable and care must be taken to conform to the experience of the foundrymen in this respect. When it is necessary to have an abrupt junction of dissimilar sections, proper filleting and judicious coring will relieve the situation to a certain extent. In addition, the foundryman will aid soundness at these points by careful chilling. It is not wise to depend too much on chilling to care for conditions of this sort as the indiscriminate use of chills may cause cracking in intricate castings when they are placed in service, particularly when they are assembled by welding.

Internal voids may have a serious effect, not only because of a decrease of effective section and consequent increase in unit stress, but because of the possibility of stress concentration in the metal immediately surrounding the void. The stress concentration caused by internal irregularities and those apparent at the surface may go as high as several hundred percent of the normal stress in the sound metal when the radius of the junction of the fissure with the sound metal is extremely small.

One source of unsoundness which is often encountered, is the presence of trapped gases in the solidified metal due to insufficient venting of the mold or lack of proper sand control. The possibility of such a condition is ever present if the foundry supervision and production methods are not of the highest order. The question of sand control is of great importance and the prospective purchaser should assure himself that this problem is dealt with effectively. The methods and mixtures in general use have been the subject of many discussions but few standards have been set up. The personal element and experience assume as large an importance as those involved in molding and melting.

The thermal conductivity of the austenitic alloys is considerably lower than that of the ordinary steels and Cr-ferritic alloys. As a consequence, a large temperature differential may exist in a structure with heavy stresses as the result of different rates of expansion. These stresses, like other effects causing an increase in the unit stress, have an exponential effect on the creep rate and cause warpage and fatigue to a greater degree than is generally realized. It is probable that, if properly analyzed, the greatest number of failures in service would be traceable to this cause. When possible, such conditions should be minimized in their effect by slotting in a direction perpendicular to the long axis of the part or even building the part up with articulated joints in order to eliminate unequal expansion.

An excellent article by Bull[4] on certain points of design which aid in the production of sound castings contains a wealth of good information, as do the comments by Brown[5], both of which should be thoroughly digested by every user and producer of metals for use at high temperatures. These publications show sketches and photographs of good and bad design that are most illuminating.

Alger and McCormick[6] have discussed the importance of good design and foundry practice and their comments are worthy of careful study.

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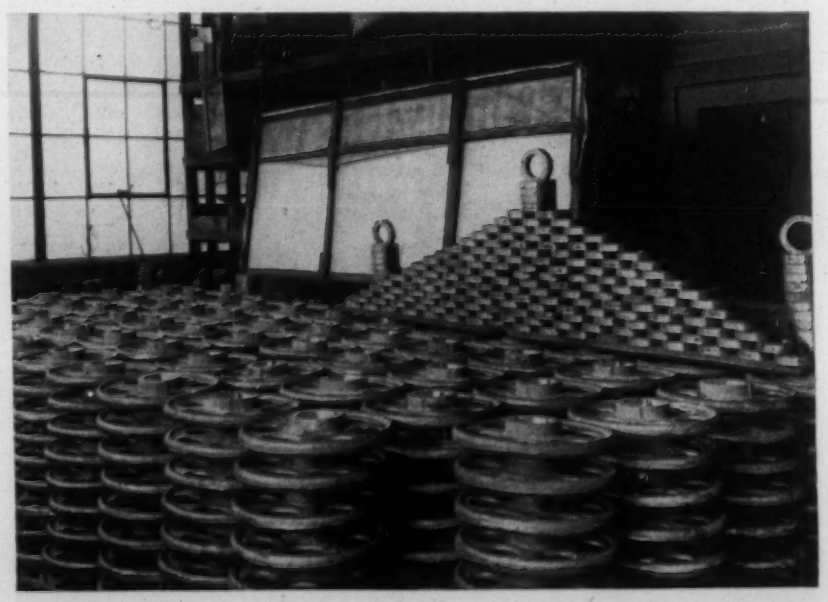
[4]R. A. Bull. The Performances of Cast Carbon and Low Alloy Steels in High and Low Temperature Service. *A.S.T.M.-A.S.M.E. Symposium on Effect of Temperature on the Properties of Metals*, 1931, pages 295-431.

[5]R. S. Brown. Discussion, *A.S.T.M.-A.S.M.E. Symposium*, 1931, pages 144-149.

[6]R. D. Alger & G. C. McCormick. High Alloy Castings—Their Foundry Problems. *Metal Progress*, Vol. 24, July 1933, pages 15-19.



Heat Resisting Alloy Collars and Discs for Normalizing Furnace. (Courtesy Pioneer Alloy Products Company.)

Structural elements for high temperatures must be designed by a somewhat different system of reasoning than that used for elements operating at normal temperatures. The usual methods based on the elasticity of metals are inapplicable to structures which deform as plastic substances under the influence of temperature, load and time. The existence of the phenomenon of "creep" necessitates design formulæ and reasoning based on plasticity rather than elasticity.

While we know all too little about creep values and critical temperature effects on metastable alloys, the errors introduced by this lack of knowledge pale into insignificance when compared to the errors arising from inherent casting defects, poor designing, warpage due to uneven temperature distribution and kindred difficulties.

Avoidance of these defects are as necessary as improvement in the alloys themselves as to strength and stability by means of adjustment of constituents.

Several means are available to determine the presence and magnitude of defects within a cast structure. Visual examination of suspected areas will generally disclose the presence of large shrinks and voids near the surface, particularly those caused by the abrupt junction of dissimilar sections. Defects of this nature are indicated by small depressions below the normal plane of the surface and may even show as voids and porosity in the skin itself. Laps and cold-shuts appear as fairly large lines or cracks of definite direction on the surface of the part. These, however, should be distinguished from the numerous hair-line cracks of random direction which are sometimes present in the skin because of low pouring temperatures. As previously mentioned, it is necessary to pour intricate castings as cold as possible. In such cases the skin formed by contact with the cool wall of the mold often contains many small and superficial cracks which have only slight depth and which are an indication of proper pouring temperature.

Other methods of inspection of great value in establishing the maximum of good foundry practice involve destructive machining and deep etching, and internal inspection by means of radiographs.

Radiographs may be made either by X-rays or the emanation of gamma rays from radium or some other sufficiently powerful radioactive source. Both methods require special equipment and a definite technique and as a rule are used to locate internal conditions not apparent from the surface. Destructive machining is then used to determine the true nature of the defect and its cause.

The radiographic method is particularly valuable for large and expensive castings which are too costly for examination by destructive machining, but the failure of which would result in costs far beyond the intrinsic value of the structure itself.

By following a systematic procedure of this nature coupled with adjustment of foundry practice and design, the production of sound castings becomes possible to a greater degree than would be otherwise available. Radiographic examination is also valuable in the development of a successful welding practice for the cast and wrought heat-resisting alloys.

The use of such inspection methods supplemented by close adherence to the practice thus shown to be the best, will result in definite assurance to the user that his metal will be free from most of the controllable defects which now force him to use heavier sections than are necessary. At present the cost per unit due to heavy sections and the uncertainty of performance due to lack of adequate information cause the average designing engineer to feel that alloys of this type are a high-priced but necessary evil. This feeling has not been removed nor has it been relieved by some of the sales policies recently in effect which sent salesmen into purchaser's offices with no knowledge of the product they were selling except that it was supposed to contain a certain amount of Cr and Ni, and with no conception of the effect and importance of good design and foundry practice.

Assurance of soundness and accuracy of knowledge of creep rates for various temperatures will allow the designer to design rather than to guess.

One limitation in the application of castings as compared with wrought alloys resides in the fact that castings have less inherent ductility and fail in creep after less total elongation. If called upon, by accident, to withstand a higher load than proper design allows, the cast alloys may break instead of stretching. Tapsell[7] and French, Kahlbaum and Peterson[8] illustrate the cracking of relatively brittle alloys under overload conditions. Tucker and Sinclair[1] also comment that while wrought alloys show a gradual transition from low creep rates to high creep rates as higher loads are imposed so that final failure is long delayed even where creep is rather rapid, cast alloys shift more sharply from a low creep rate and very long life to a high creep rate and early failure. Tapsell remarks that a higher factor of safety is called for in the use of cast than of wrought alloys. Caution is therefore necessary in utilizing the greater strength of the cast alloys, although in certain types of continuous furnace mechanisms, it would not seem to make much difference whether the parts sagged out of shape or fractured, as either condition would soon make the furnace inoperative. The author's preference is for the more rigid condition indicated by a fracture failure rather than a sag failure. This of course does not apply to pressure vessels.

In conclusion, the author wishes gratefully to acknowledge the help of Dr. H. W. Gillett in the editing of these two papers. The assistance and information provided by the Ohio Steel Foundry, Michigan Steel Castings Company, The Driver-Harris Company, The Standard Alloy Company, Michiana Products Corporation, Republic Steel Company, Surface Combustion Corporation and Mr. T. Holland Nelson have been of great value in this attempt to bring to the user of heat-resisting alloys some means of properly evaluating the mass of information and near-information which has made the subject seem so hopelessly confused.

All in all, the whole heat-resistant alloy design problem is a highly complex one in which a multiplicity of factors must be considered in the attempt to "make the punishment fit the crime"—although Gilbert and Sullivan in their palmiest days never attempted the complexity of plot and music which could compare with some of the combined heat and corrosion problems.

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[7]H. J. Tapsell. Creep of Metals. Oxford University Press, 1931.

[8]H. J. French, W. Kahlbaum & A. A. Peterson. Flow characteristics of special Fe-Cr-Ni alloys and some steels at elevated temperatures. *Bureau of Standards Journal of Research*, Vol. 5, July 1930, page 125.

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Seventh Annual Meeting of the Metallurgical Advisory Board

Metallurgists from all parts of the country will gather at the Carnegie Institute of Technology on October 20 for the seventh annual open meeting of the Metallurgical Advisory Board. At the opening session to be held in the Carnegie Union, Jerome Strauss, chief research engineer of the Vanadium Corporation, will preside. Dr. F. N. Speller, chairman of the Advisory Board, will make the address of welcome.

The opening report will be made by Dr. Robert F. Mehl, director of the metals research laboratory at Carnegie. During the first year of its reorganization the laboratory has undertaken a number of new lines of research. The studies of iron-manganese and iron-manganese-carbon alloys has been continued throughout the year and will be reported. In addition to these research subjects the laboratory has inaugurated two new general programs, on precipitation from solid solutions and on internal strains in metals.

New work will be reported by Dr. Francis M. Walters, Jr., on the study of the formation of ferrite from austenite in low carbon steels in which a new dilatometer will be described which bids fair to be of considerable use in metallurgical investigations.

The studies on internal strain, to be reported by Dr. C. S. Barrett, have to do principally with X-ray determinations of internal strains in worked and heated metals and alloys. A new X-ray method will be reported which offers an opportunity to determine stress distribution in the surface of stressed materials.

At the afternoon session L. F. Reinartz, representing the open hearth committee of the American Institute of Mining and Metallurgical Engineers, will preside. Dr. V. N. Krivobok, head of the graduate metallurgical work at Carnegie, will report on his recent studies of corrosion-resisting and heat-resisting alloys.

The work of the research staff of the Metallurgical Advisory Board for the year has consisted chiefly in open hearth studies designed to enable the operator to control the finishing stages of liquid steel manufacture to a much finer degree than has been heretofore possible. To date, methods have been worked out in detail for high carbon steels, and studies have been started on low carbon steels for deep drawn products.

As a corollary to this work the problems of variation in response to heat treatment and age hardening are being studied with particular respect to the effect of the oxygen content of liquid steel. In this connection non-aging steels have been produced which have superior properties to the ordinary structural steels with regard to the ductility of the steel and its ability to withstand high temperature heat treatment without detriment to its physical properties. This work will be described by Dr. Charles H. Herty, Jr., director of coöperative research, and his assistants.

READERS' COMMENTS

Heat Resisting Alloys

To the Editor, METALS & ALLOYS:

Due to recent developments, much of the data assembled in Stanbery's article is obsolete.* It is well known that short time tensile tests at high temperature constitute a most unreliable source of data for design purposes. The long time creep test figures cover rolled or forged material and cannot be applied to cast alloys, even of identical analysis, without serious error. Chromium-nickel alloys cannot be arbitrarily segregated into five broad classes solely on the basis of their chromium and nickel content with the assumption that the metallurgical and physical properties in any given group are substantially similar.

I am of the opinion that the suggested basis of design is wholly incorrect. Short time ultimate strength is the poorest available factor upon which to base safe working fibre stress. No creep investigator's work will sustain the theory that creep varies as the fifth power of the applied load with any approach to constancy sufficiently close to permit using this theory as a basis of design. High temperature physical properties determined for chromium-nickel alloys apply only to the specific composition tested and not to a broad group as suggested. To use the chromium and nickel content as a basis for this grouping is particularly in error since high temperature strength is influenced more profoundly by minor elements.

Broad statements attempted by the author concerning the nature and physical characteristics of protective oxide on the surface of heat enduring alloys should not be accepted without adequate technical support. I question the statement that nickel in excess of chromium causes a flaking scale under quick changes of temperature.

In the enameling industry flaking scale is particularly objectionable since it is deposited upon the enameled ware. Extensive, authoritative tests covering scaling and flaking of all available chromium-nickel alloys indicate a certain chromium-nickel composition to give the least difficulty in this respect. The tests revealed that this alloy in cast form was much less inclined to flake than the same composition in the form of hot rolled bar stock. From this it would appear evident that something other than nickel content influences the physical characteristics of the scale.

In our work we have not noted that precipitation of carbides in austenitic chromium-nickel alloys is "usually" accompanied by decay of the austenite nor that the carbides returned to solution when the alloy is heated "above 1600° F. for a fairly long time." We do not find the precipitation of carbon in stable austenites to be slow at any temperature within the precipitation range. In the case of cast alloys the amount of carbon is always very substantially in excess of that which is soluble and the resulting carbides are invariably massive formations at the grain boundary not "usually small carbides almost wholly confined within the grain."

I am not aware of anything in the way of published literature which justifies the author's opinion that silicon combined with molybdenum or tungsten will greatly enhance high temperature creep values. Such data as has been published indicates that manganese is not a suitable substitute for nickel in the production of austenitic stainless steel. Our experience would not bear out the wide limits suggested for silicon and manganese content. However, again, it depends upon other elements present and the question reverts to the fact that it is impossible to generalize on this subject. The author is inclined to dismiss the so-called "minor elements" in chromium-nickel alloys with too scant attention. They are, in fact, more potent in their influence upon high temperature physical properties than the chromium and nickel content.

In the alloy foundry the acid melting process is almost universal and charging materials commonly employed are so low in phosphorus and sulphur that removal or control of these elements is not a factor in manufacture. The question of melting facilities in alloy foundry service might be simply stated by remarking that the arc type acid furnace is almost universally employed with a few induction type acid furnaces making their appearance. Comment on the relative merit of acid and basic melting processes has no particular significance. No alloy foundryman would employ the basic method for the reduction of phosphorus and sulphur since these elements are not a factor of concern with charging materials commonly employed.

The author, perhaps, unintentionally, creates the general impression that the manufacture of alloy castings is an intricate matter seldom attended by successful results even when the details of manufacture are in experienced hands. While this is not true it is, nevertheless, dangerous to attempt general advice on the subject of designing alloy castings to meet foundry requirements. Engineers and foundrymen of the broadest experience would hesitate to attempt this task. The fundamental design of any casting is, naturally, determined by service requirements. If the design is unusual or intricate, the safest procedure is to submit a sample casting to careful examination. Frequently, it is necessary to compromise between the demands of the designer and the ideal design of the foundryman.

Above I state that I consider it impossible and very impracticable to classify alloys by their chrome-nickel content and then draw broad conclusions as to their physical properties. This is a popular conception of many engineers using heat enduring materials. By so doing, they believe they can give the purchasing department a specification under which a number of manufacturers can bid. All being considered equally satisfactory, the lowest bidder is preferred.

If strength is a factor, it is probable that the design has been made before it gets to the purchasing department—based on about the lowest of what the prospective bidders claim as to high temperature strength. Unfortunately for this theory of alloy specification it is demonstrated in practice that the high temperature strength of a given chromium-nickel alloy can be affected several hundred percent by variation of minor constituents and manufacturing practice. The author gives some broad limits for these minor elements but does not give the optimum composition. Indeed, he could not because the optimum composition changes with the major constituents and with the service for which the alloy is intended. Yet, when he comes to consider strength these facts are ignored in attempting a general grouping of alloy compositions.

These groups are not even specific as to the chromium, nickel and carbon content but cover a considerable range for each element, implying that anything in that range will have about that strength. Even if the chemical composition is closely defined to the last element there will be wide variation in the strength results—depending upon manufacturing variables. It is for this reason that The Calorizing Company has adhered to the practice of omitting chemical analysis in its publications. We do give exact physical properties of alloys under a definite trade name and code letter which indicates a definite analysis melted and cast in a definite manner. Unless all the elements, conditions of melting and casting and all manufacturing control are set forth in a veritable book of specifications, uniform physical properties in the finished product cannot be assured.

The Calorizing Company has spent a great deal of effort in raising the strength of its chrome-nickel alloys and determining the high temperature physical properties of these improved alloys. We are of the opinion that the best basis for designing high temperature alloy structures is found in the use of long time creep test values. Our experience teaches that information of sufficient accuracy for the designing engineer is only to be had by running a long time creep test for each alloy at each temperature for which it is to be employed. Further, it is absolutely essential that the daily melt of the foundry be closely controlled to the analysis of the creep test specimens, otherwise, the commercial castings will not uniformly possess the physical properties ascribed to them.

Our long time creep test work on cast chromium-nickel alloys has covered the temperature range 1400° to 2000° F. It reveals no foundation for the assumption that rate of creep is on the order of the fifth power of the unit stress. As to considering the strength of chromium-nickel alloys in groups, four Calite alloys covered by one of our tests—differing widely as to high temperature strength—come within the bounds of one single group suggested by the author.

Sept. 20, 1933,
Pittsburgh, Pa.

B. J. SAYLES, President
Calorizing Company

(Continued on page 166)

*Editor's note: Stanbery's article includes all recorded creep values.

Quench in Oil

Editor, METALS & ALLOYS:

We are very glad indeed to see from Dr. Gillett's editorial in your July issue on the subject of Quenching Oil that someone is endeavoring to direct the attention of metallurgists to the importance of the quenching operation. Unquestionably quenching is the least understood operation in the heat treatment of steel. Great care is taken in every step in the manufacture of a steel product up to the time it is quenched. Then when its structure is to be entirely changed in a very few seconds no attention is given to whether the quenching liquid used possesses the right cooling rate both above and below the critical range to develop the proper hardness in the steel being treated.

As an organization which has spent nearly 25 years in the development of Quenching Oils we cannot, however, exactly agree with Dr. Gillett's suggestion that the purchasing of Quenching Oil should be reduced to specifications. While it is true that it is a simple matter to analyze any oil and set down its exact specifications, it is equally true that a number of oils meeting exactly the same physical specifications will not necessarily give the same results in actual service. If it were possible to buy Quenching Oils on specifications, it would be a simple matter for any refiner to analyze a successful Quenching Oil such as our No. 2 Soluble Quenching Oil and simply make an oil to meet its specifications. However, every metallurgist who has tried such substitute Quenching Oils knows this is not possible and prefers buying an oil which he has found from experience will give him results rather than one which meets a certain set of specifications.

The most important property of any Quenching Oil is its stability; that is, its ability to continue to give uniform results after years of continuous use. It is well known that all mineral oils are made up of innumerable hydro-carbons of different boiling points and as a result when a mineral oil is used for quenching the "light ends" or constituents of lower boiling point are volatilized and driven off with the result that the oil gradually thickens. Its cooling rate will naturally decrease with the result that after a few months' use the mineral oil will not develop the proper hardness in a steel part.

So we see that though a quenching oil might be made to meet a set of specifications and might even give satisfactory service when new, if it were to change after a few weeks' use, as nearly all oils do, the metallurgist would have no protection, for the supplier would simply have to prove that the oil met the specifications at the time it was delivered and his responsibility would cease.

One of our good friends who is a metallurgist of a well known automobile part maker recently tested a quenching oil which was represented to him to be an exact duplicate of Houghton's No. 2 Soluble Quenching Oil. It is true that the 2 oils were of exactly the same physical specifications. However, after about 2 months he began to get complaints from the Inspection Department of insufficient hardness so he had a sample of the oil checked. The analysis showed that the oil had increased in viscosity from about 100 seconds at 100° F. to nearly 143 seconds and its flash point had raised 25° F., whereas the No. 2 Soluble Quenching Oil which he had been using for over 5 years had changed only 2 seconds in viscosity, in that time. Naturally as this mineral oil thickened its cooling rate decreased with the result that it did not cool steel sufficiently rapidly to develop the proper hardness.

We are sending these thoughts along to you in a friendly spirit as we know that the chief enjoyment in publishing a technical magazine is to stimulate discussion. We appreciate your directing the attention of metallurgists to the importance of the quenching operation and hope that you will publish more information on this subject.

E. F. Houghton & Co.
Sept. 12, 1933

G. W. PRESSELL,
Asst. General Manager

Heat Resisting Alloys

Editor, METALS & ALLOYS:

The second paragraph of Stanbery's article in the September issue of METALS & ALLOYS opens up a subject in which the writer has been interested for a number of years, namely the strength of heat resisting alloys at high temperatures. By careful metallurgical control and ordinary efficient attention to the practical work of melting and pouring, the variation in strengths of alloys should not vary any more than any other kind of steel.

August 18, 1933
Chicago, Ill.

D. EVANS, President
Chicago Steel Foundry Company

Editorial Comment

(Continued from page A9)

over a period of some 20,000 hours states that he must have a test that will consume no more than 50 hours, a 4,000 to 1 extrapolation, and turbine makers, concerned with, say up to 200,000 hours of service, chafe at tests of 2,000 hours duration. Depending on the composition and structure of the alloy, there are strengthening, strain-hardening tendencies; softening, annealing tendencies; and embrittling and strengthening precipitation-hardening tendencies, each affected, no doubt, by the stress imposed, and, to a remarkable degree, by very tiny changes in temperature. Once these different tendencies can be separated and the rates of each determined separately, we can then count on the consistency of Nature to follow her own laws every time. But if we slam-bang through a test under conditions such that strain hardening predominates and do not consider the diffusion and precipitation rates, that may be very slow and not detectable under the conditions chosen, but rapid and predominating under other conditions, we cannot expect to get the right answer.

If we ask our questions of Nature by testing under excessive loads and temperatures, far greater than we expect to use, even though we know that this exaggeration of conditions sets up reactions of great speed, we will only get the reply to the exact question we put. But if we choose our test questions so as to bring out the different types of phenomena that take place, and do not press for too speedy evidence of a slowly-occurring phenomenon, perhaps we shall come to see light on the relatively new creep problem in some such manner as we are beginning to do on the older corrosion and fatigue problems.—H. W. GILLETT

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Appointment of **J. Ralph Patterson** as general manager of sales for the 130-year-old Mackintosh-Hemphill Company, rolling mill engineers and builders, has been announced by Colonel James S. Ervin, president.

Mr. Patterson enters a field of selling far different than the predecessor who held the post when the company made cannon and balls for Perry's fleet and the defense of New Orleans in the War of 1812. He is confronted with possible achievements as great as when this firm transferred the steel mill supremacy of the world from Europe to America by building the original Homestead Steel Works at Homestead, Pennsylvania, and selling it to Andrew Carnegie on the installment plan of buying.

The new sales manager has had 20 years of experience, beginning in 1913 with the erection of steel mills, and transferring his attention to the making of mill equipment for the past 11 years with the Mackintosh-Hemphill Company. He first was assistant and then manager of Adamite sales and most recently manager of roll and alloy casting sales.

Since the Homestead plant was built the company has produced nearly 1,000 complete mills for steel, copper, brass, lead, tinfoil and aluminum industries throughout the world. It made the first chilled iron and the first locomotive built west of the Allegheny mountains. It is responsible for many of the great mechanical inventions in modern steel mills.

The company has three plants. The one in Pittsburgh produces every variety of chilled iron and alloy chilled iron roll. Its Midland, Pennsylvania, plant manufactures steel castings and steel and steel alloy rolls. A plant at Wooster, Ohio, is reputed to be one of the most modern and best equipped for the making of heavy duty mill machinery. Its assembly floors provide facilities for the assembly and erection of machine units as completed.

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Maj. A. E. Carpenter, Vice President and General Manager of E. F. Houghton and Co., Philadelphia, Pa., sailed September 13th to spend several weeks in England inspecting the new plant of Messrs. E. F. Houghton and Co. of England, Ltd., in Manchester.

A.F.A. Information on Foundry Dust Problem

An up-to-date and authentic publication dealing exclusively with the important subject of dust abatement and control in the foundry industry has just been issued by the American Foundrymen's Association as a 30-page pamphlet entitled "Foundry Housekeeping Conference." The pamphlet contains the three papers presented at the Good Housekeeping Conference held by the A.F.A. at the recent foundrymen's convention in Chicago.